Issued May 15, 1913.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF PUBLIC ROADS—BULLETIN NO. 48.

LOGAN WALLER PAGE, Director.

REPAIR AND MAINTENANCE OF HIGHWAYS.

BY

LAURENCE I. HEWES, Ph. D.,
Chief of Economics and Maintenance, Office of Public Roads.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., March 10, 1913.

Sir: I have the honor to transmit herewith the manuscript of a bulletin entitled "The Repair and Maintenance of Highways." This publication will, I believe, supply necessary information to rural officials and others concerning a topic which has been much neglected. References to recent highway developments in Massachusetts and New York as well as in Great Britain and France are included so that the examples thus set forth may be known in various localities of the United States. This bulletin should tend to prevent waste of money and the misunderstanding of proper maintenance methods. I therefore respectfully recommend its publication as Bulletin No. 48 of this Office.

Very respectfully,

Logan Waller Page,
Director.

Hon. D. F. Houston,
Secretary of Agriculture.

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REPAIR AND MAINTENANCE OF HIGHWAYS.

INTRODUCTION.

The need of effectual repair and maintenance of highways has now become well recognized. The resulting demand for better methods and more certain results is insistent. It is the purpose of this bulletin to consider repair and maintenance of highways as a subject separate from their construction. It will be necessary to consider matters related to construction, but it is not intended to supply information on this subject.

During the last two decades there has been a remarkable development of highway building which is intimately associated with State aid and State control, especially in the region north of the Ohio and east of the Mississippi Rivers. The evolution of present-day conditions in the above States is particularly important in its bearing on highway repair and maintenance. It has been carefully studied, and certain important derived statistics are presented in this bulletin in tabular form.

Examination of public reports and available information in the several States does not develop sufficient data to warrant any general attempt to separate maintenance and repair expenditures from construction cost. It is, moreover, not possible to adopt any uniform method of presenting maintenance and repair data in any group of States. With a few exceptions, up to the present time there has been no systematic separation or record of maintenance and repair costs on public roads.

The rapidly increasing automobile traffic on highways has measurably stimulated interest in road improvement and profoundly modified methods of construction and maintenance. The action of automobiles upon road surfaces and the reaction of road surfaces upon automobile tires is therefore discussed in some detail, and certain major statistics are presented.

There is need for much improvement in road management. Where good business organization has been applied to the work of repair and maintenance, it has always responded with better results. Since it is commonly held that future advance in road betterment is largely dependent upon successful management, corresponding emphasis is here given to that subject. The discussion of road management, however, is purposely arranged to follow the details of repair and maintenance.

With reference to roads of the first class, there are now many questions concerning repair and maintenance which depend largely upon the requirements of the bituminous-bound macadam road. Possibly the bituminous type of road will be modified or ultimately superseded by some improved form of construction. It now meets many necessary requirements of modern traffic.

The financing of road improvements is assuming increased importance. It necessarily involves consideration of all future operations of repair and maintenance. Some attention has therefore been directed to that subject, particularly in regard to bond issues. The present indications are that intelligent road financing must depend upon more accurate and comprehensive traffic census data than have yet been used and that future repair and maintenance charges must be frankly considered at the outset.

It is now recognized that there is a sharp distinction between the terms *repair* and *maintenance*, as applied to operations upon highways. When a road of any type is completed, the effect of travel and the elements tend to destroy it. Those operations required constantly to oppose the deterioration of the road constitute general *maintenance*. Without maintenance, the road after a time is partially destroyed, and operations then necessary to restore it constitute *repair*. It is true that both processes are often similar in kind and may overlap. They differ in quantity and in the order in which they are applied. A road properly maintained may not need repair for an indefinite interval, but a road properly repaired always needs maintenance. The term "strict maintenance" may be used to denote those operations that continuously keep a road true to its type, whether or not such operations restore the constant wear of the traveled way. When the hard surface of a road becomes worn so thin that resurfacing is necessary, such operation must at present be classed as *repair*, even though resurfacing operations may at times involve practically a reconstruction of the road surface. If a macadam road were paved with brick or rebuilt of concrete or other material and the result were decreased annual maintenance, such work would be essentially reconstruction. To indicate the kind of maintenance which constantly replaces a worn surface and so preserves the integrity of the road, the term "absolute maintenance" seems justified and is so used.

This bulletin deals with the repair and maintenance of three classes of roads: (1) Macadam roads of all kinds, (2) gravel and sand-clay roads, and (3) earth roads.

Besides the above three classes of roads, there are various associated classes of roads, such as sand-oil roads, oil-gravel roads, brick roads, concrete roads, etc., whose repair and maintenance are considered in connection with a corresponding major class. The repair and maintenance of pavements are treated only in so far as such pavements have been used outside of cities.

MACADAM ROADS.

It can not be said that macadam roads in this country have been properly maintained. Maintenance has usually been strongly advocated and little practiced. Maintenance and repair have not been distinct operations. They are just beginning to be carried as separate accounts on public records.

Previous to about 1905 a macadam road signified a broken-stone road bound with screenings or "fines" rolled wet. Such a road is now called a water-bound or ordinary macadam road, to distinguish it from roads bound with some bituminous material, which are in turn called bituminous-macadam roads and sometimes tarred roads, or tar-macadam roads, or pitch-macadam roads.[1]

REPAIR OF ORDINARY MACADAM ROADS.

Ordinary macadam roads have until recently formed the highest class of improved country highways. Although such roads are now, in many instances, giving place to bituminous-macadam or other kinds of road,[2] they still constitute an important class of roads and their repair and maintenance involve the fundamental principles for all road work.

When a road has worn more or less out of shape in section and is rutted, new stone is usually required to resurface it. The first problem is to determine how much stone will be needed. The average stone depth on the road may be measured or calculated by a known wear coefficient or by a careful inspection of the general road surface. Accurate measurement of the stone remaining on the road can not be made by digging a few small holes in the surface, because the subgrade invariably works into the lower stone, and also the lower stone layer penetrates the subgrade. A clean-cut trench (halfway across the road section) with careful measurement will give a good determination. In England, at intervals, Government highway bench marks are established, at which cross sections are taken from time to time to determine the wear of the surface. An annual wear coefficient expressed as a fraction of a ton per square yard or as tons per mile

[1] The term "positive binder" is also in use to designate a binder other than water and stone dust.

[2] Cuyahoga County, Ohio, has to-day about 400 miles of brick road begun 18 years ago. Several other counties in Ohio, Indiana, and Illinois have used brick for many years on *some* roads. Niagara and Erie Counties, N. Y., have also recently had built many miles of brick roads about the city of Buffalo. Wayne County, Mich., has since 1909 been building 16-foot concrete roads in increasing mileage yearly. Such roads have also been built at Davenport, Iowa, and Boise, Idaho, and in several Eastern States.

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may be gradually established for the various macadam roads under the control of each road official. On a long unevenly worn road, if the estimate of new stone is to be formed by inspection, stations may be run along the center of the macadam, and against each station the percentage of new stone may be entered. The estimate of new stone should be checked by all the information available, in particular by actual measurement at typical sections and by wear coefficients of similar roads.

The usual method of beginning repair is to pick up an old road surface with spikes set in the rear wheels of the roller (fig. 1), and

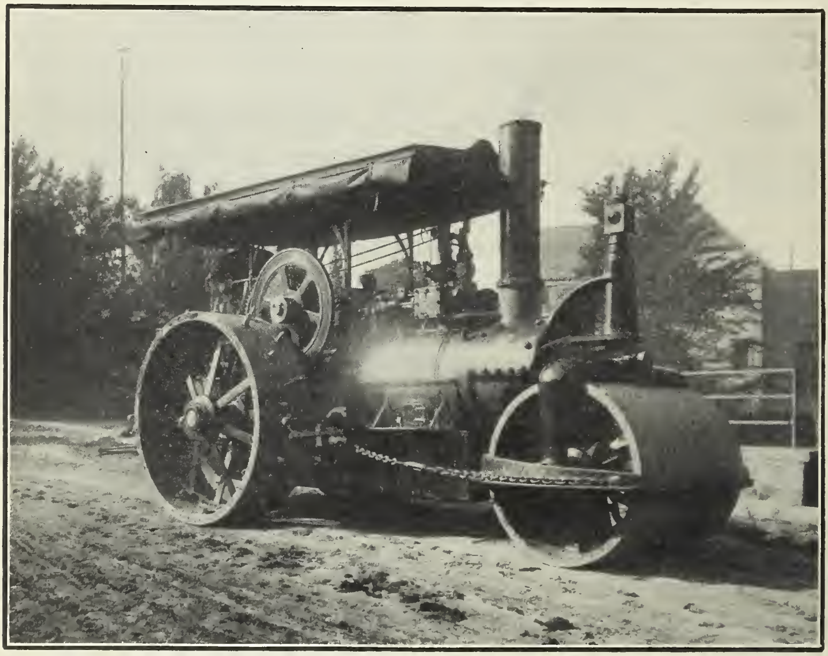

FIG. 1.—Road roller, showing spikes set in rear wheels.

then finish the work of loosening by hand or by the use of a harrow or plow. The surface must first be thoroughly cleaned of dirt and organic matter. Mechanical sweepers do the work of sweeping rapidly and cheaply. Various forms of machine scarifiers are also used, and nearly all of them are operated by a steam roller. Their essential features are sufficient strength and rigidity thoroughly to break up the hardest surface. It is desirable that the scarifier be light enough to be removed from the road without the use of a roller. Some scarifiers are fitted with steering devices, and the breaking depth of the spikes can usually be regulated. These machines cost from $275 to $400 and are economical if considerable work is to be done annually. The cost of scarifying varies from about one-half to $2\frac{1}{2}$ cents per square yard, depending on the kind of stone, the depth of scarifying, and the cost of supplementary hand picking. If plowing is done, care must be taken to avoid sending the plow into the subgrade, for the earth thus mixed with the stone weakens the construction. Forms of scarifiers are shown in figures 2 and 3.

After the old road is thoroughly broken up by the scarifier or otherwise, the material may be reshaped to crown by using forks and rakes so that the "fines" fall to the bottom of the layer, or the old material may be screened with a hand screen and the road then reshaped. Usually it is possible to rake stone from the sides toward the center to restore the crown partially; then new stone, of preferably the same kind as already in the road, should be added. When new

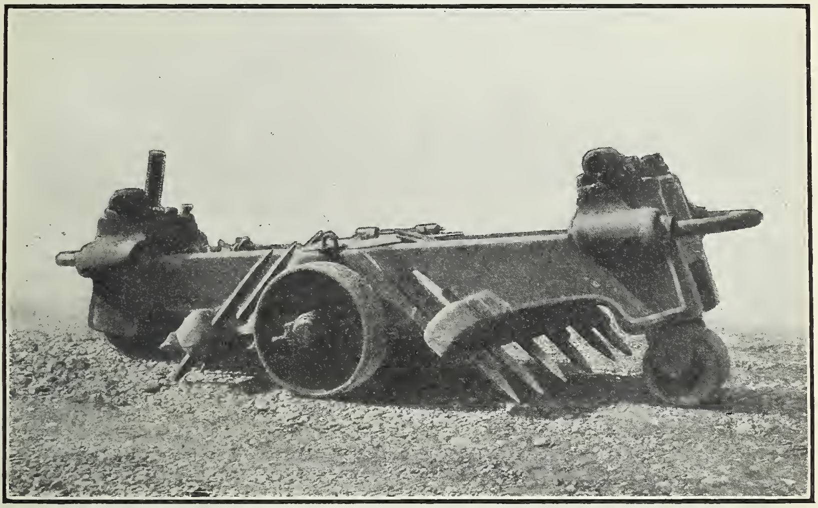

FIG. 2.—Type of scarifier.

material is applied, however, as a separate and homogeneous course of uniform depth, it need not be of the kind already in the road. The stone first added may be sufficient to re-form a No. 1 or bottom course when rolled with the old stone, or it may be of sizes and amount adapted for finishing the road at once.

On old roads which have been worn very thin, it is good practice to add first enough stone to rebuild the bottom course, for example, to a minimum of 3 inches in depth when rolled, and then to apply a second course as in construction. Grades and lines are usually needed on repair work and, where stone is to be spread as a second course, it will be advisable to use spreading blocks of size equal to the depth of the loose stone.

There are many variations from the above outline of the resurfacing method. When the road presents an even surface and is not much worn at the sides, the center or horse track may be thoroughly scoured with stiff brooms until the bare mosaic surface appears, and No. 2 stone of the same kind as that used in the construction may be applied directly to restore the crown. The application should be of sufficient depth to create a mechanical bond and must be rolled.

FIG. 3.—Another type of scarifier.

When the wear has been uniform, expense may sometimes be saved and the solidity of the road preserved by confining the scarifier to a shallow strip on the outside edges of the road after first thoroughly sweeping the surface clean of all dust and dirt. If it is possible to soak the road before applying new stone, it will greatly help in bonding new material to the old surface. In any case there must be no layer of dust or refuse on the old road when the new stone is applied; otherwise there will be an imperfect bond and the new layer will break up.

Sometimes the scarifying may be reduced to shallow, hand-picked grooves parallel to the road and a foot or more apart, or else it may be entirely omitted. In the latter case the road should be first patched to fill up all depressions and the patches rolled. The roadway is then thoroughly cleared of all dust, dirt, and refuse, and abundantly soaked, and then the new stone is spread true to crown and grade.

All resurfacing should be finished with a binding course of screenings worked in with water from the sprinkler and thoroughly rolled. A thorough bonding by the use of successive light applications of screenings with alternate wetting and rolling with a steam roller is essential. It is preferable to turn aside all travel during the work.

The following table shows the cost of resurfacing ordinary macadam roads by the Massachusetts State Highway Commission. In general, this resurfacing was done by first loosening the old surface with picks in the roller, reshaping the crown without screening, and then adding new stone in the form of a top course.

TABLE I.—*Table showing costs of resurfacing with broken stone (extraordinary repairs) Massachusetts State roads.*[1]

Year and town or city.	Year of original layout.	Area (square yards).	Tons of stone.	Broken stone per square yard per year (tons).	Cost.			Kind of stone used.
					Per square yard (cents).	Per square yard per year (cents).	Broken stone in place (per ton).	
1902.								
Leicester	1895 (?)	8,400	1,495.33	0.0300	30.0	5.170	$1.69	Trap.
Fitchburg, West	1896	3,600	582.15	.0230	36.0	5.150	2.23	Do.
Beverly		4,302	716.38	.0300	30.0	5.200	1.80	Do.
1903.								
Charlemont		4,450	1,216.00	.0570	55.2	11.600	2.02	Do.
Deerfield		4,500	1,401.00	.0390	56.1	7.010	1.80	Do.
Northampton		6,667	825.00	.0157	23.0	2.870	1.86	Do.
Buckland		1,592	216.00	.0140	32.1	3.250	2.37	Do.
Phillipston		10,667	311.00	.0290	4.3	.970	1.50	Local.
Westport		2,667	609.00	.0290	59.0	7.390	2.59	Trap.
Fairhaven		4,500	879.00	.0240	29.8	3.720	1.52	Local.
Mattapoisett		3,833	738.00	.0240	24.3	3.030	1.26	Do.
Leicester		3,653	797.00	.0730	36.0	12.012	1.65	Trap.
Spencer		3,417	745.00	.0540	35.9	8.968	1.65	Do.
Andover		5,398	1,000.00	.0310	36.0	6.007	1.95	Do.
Methuen		9,617	1,620.00	.0290	35.3	5.839	2.02	Do.
Russell		3,923	1,050.00	.0330	46.8	5.848	1.75	Do.
Huntington		8,112	1,504.00	.0270	33.2	4.904	1.79	Do.
Paxton		28,541	2,172.00	.0120	14.8	2.411	1.95	Do.
Worcester		11,929	1,638.00	.0240	25.3	4.412	1.84	Do.
1904.								
Worcester	1897	5,833	606.00	.0208	29.0	3.530	1.70	Local.
Holden	1898	3,682	503.00	.0273	25.8	5.164	1.89	Do.
Westport	1894	6,000	1,124.00	.0208	44.0	4.893	2.35	Trap.
Fairhaven	1894, 1895	8,167	1,362.00	.0196	27.5	3.234	1.65	Local.
Rehoboth	1895, 1896	7,833	1,226.00	.0332	27.6	5.854	1.76	Do.
Williamstown	1895, 1896, 1898	8,333	1,009.00	.0175	31.9	4.625	2.64	Trap.
West Springfield	1895, 1896	12,380	1,316.00	.0135	17.4	2.218	1.64	Do.
Lowell (south)	1897	8,114	1,157.00	.0238	26.9	4.476	1.88	Do.
Gloucester	1894	5,833	847.00	.0161	30.5	3.384	2.10	Do.
Shelburne	1894	7,924	965.00	.0135	25.3	2.811	2.08	Do.
Deerfield (south)	1895	4,233	800.00	.0236	38.5	4.809	2.04	Do.
Westminster	1895, 1896	6,667	701.00	.0140	23.6	3.160	2.25	Do.
1905.								
Auburn	1895, 1896, 1897	16,947	4,696.40	.0351	44.4	5.625	1.49	Local.
Chicopee	1897, 1898, 1899	5,917	1,040.80	.0215	36.0	4.404	2.04	Trap.
Chelsea	1901	8,820	2,877.70	.1088	55.0	18.322	1.60	Do.
Beverly	1895	6,722	931.40	.0153	29.0	3.218	2.09	Do.
Great Barrington	1894, 1896	15,615	1,300.00	.0115	18.6	2.476	2.24	Do.
Hadley	1894	4,647	1,649.30	.0394	63.54	7.052	1.78	Do.
Marion	1903	1,305	200.00	.0170	26.8	2.979	1.75	Local.
North Adams	1894, 1896	15,000	1,800.00	.0139	25.1	2.904	2.09	Trap.
Pittsfield	1894, 1898	11,402	1,020.00	.0108	19.1	2.309	2.14	Do.
Sturbridge	1897	5,157	1,107.00	.0307	34.0	4.852	1.50	Local.
Quincy	1899	8,400	1,353.00	.0322	35.4	7.087	2.20	Trap.
Rochester	1903	5,595	1,067.60	.0239	33.4	4.173	1.75	Local.
Townsend	1896, 1897, 1898	6,167	821.70	.0174	25.4	3.308	1.91	Trap.
Westport	1894	6,030	1,065.50	.0221	41.5	5.190	2.35	Do.
1907.								
Phillipston	1897, 1898	4,447	900.00	.0220	43.52	4.730	2.15	Local.
Sudbury	1897, 1903	6,020	424.00	.0768	15.50	1.980	2.20	Trap.
Do	1898, 1900, 1901, 1902	38,195	1,774.00	.0095	15.37	3.147	3.31	Do.
Sutton	1899	4,333	847.00	.0279	31.13	4.447	1.35	(2)
Wayland	1903	1,503	248.00	.0413	36.31	9.080	2.20	(3)
Watertown	1895	1,757	375.00	.0178	42.69	3.557	2.00	Trap.
Westwood	1899, 1900	9,167	1,603.00	.0225	28.58	3.672	1.60	Local.
Williamsburg	1896	4,583	752.00	.0149	36.76	3.790	2.20	(2)
Goshen	1895	5,197	853.00	.0149	36.76	3.790	2.20	(2)
Weymouth, North	1895	9,692	1,764.00	.0152	43.67	3.640	2.40	(4)
Averages	6.27[5]	[6] 417,385	[7] 207.00	.0235	28.88	4.59	1.96	

[1] Annual reports of Massachusetts State Highway Commission.
[2] Local field.
[3] Winchester trap.
[4] Tidewater trap.
[5] Average resurfacing period in years.
[6] Total square yardage for all roads.
[7] Tons per mile per year for 15-foot road.

Table II shows the cost of a number of resurfacing jobs in New York State by the department of highways:

TABLE II.—*Resurfacing costs in New York State (plain macadam) 1909.*[1]

Road No.	Year when built.	Resurfaced.		Age (years).	Cost.			
		Widths (feet).	Miles.		Per mile.	Per square yard (cents).	Per square yard per year (cents).	Total cost of job.
187	1904	14	1.72	5	$3,417	41.6	8.32	$5,877
188	1904	12	4.25	5	3,969	56.2	11.44	16,870
218, 224	1904	11	4.41	5	2,678	41.5	8.30	11,808
112, 598	1905	12	6.07	4	2,710	38.5	9.62	16,450
184, 185	1904	12	2.15	5	2,889	41.0	8.21	9,100
63, 78, 79	1902	16	7.385	7	3,169	33.8	4.82	23,405
7, 41	1901	15	3.02	8	3,247	36.9	4.61	9,806
98, 168, 172	1903	15	3.885	6	2,561	30.2	5.04	9,950
23	1900	20	1.45	9	2,458	20.9	2.32	3,564
16, 118	1901	13	7.253	8	3,002	38.1	4.76	21,773
116, 141	1902	14	4.407	7	3,057	37.2	5.32	13,472
17, 18, 19, 34, 52, 53	1901	14	12.687	8	3,539	43.1	5.39	44,893
20, 35, 50	1901	14	8.2	8	3,767	45.9	5.73	30,886
51, 144, 150	1902	13	6.3	7	2,381	31.4	4.48	15,000
54, 143, 148, 149	1903	12	8.7	6	2,972	42.2	7.03	25,853
233	1904	16	3.904	5	2,751	29.3	5.86	10,739
91	1902	16	3.9	7	3,697	39.4	5.62	14,417
49, 75, 121	1902	16	4.2	[2] 8	3,972	42.3	5.29	15,968
78	1902	16	1.25	[2] 8	3,298	35.1	4.39	4,122
Averages			[3] 779,595	6.76	3,167	39.0	5.77	[4] 303,962

[1] Compiled from the Reports of the State Commissioner of Highways, 1909 and 1910.
[2] Resurfaced 1910.
[3] Total number of square yards.
[4] Total cost of all work.

The repair or resurfacing of macadam roads was carried out on the continent of Europe up to within a decade by a system of continuous patching. There was no period for the general resurfacing of an entire stretch of road. New stone was skillfully applied by the hand work of experienced roadmen. As a rule patches were made under a well-defined plan which contemplated a complete renewal of stone after necessary periods. The road was carefully scarified by hand picking and the patches were accurately applied, but no rolling was undertaken and the bonding of the repairs was left to the traffic. To make sure that travel passed over the new patches, material was applied in checkerboard fashion. Without the use of a steam roller, but in the hands of men many of whom had spent their lives upon the road, the system of repairs "in point of time" produced remarkable roads, particularly in France. The system is now rapidly giving way to a system of periodical surfacing with the use of a steam roller, accompanied by continuous small repairs or maintenance.[1] It is not difficult to understand how the terms maintenance and repair have become confused. The average system of resurfacing "in point of time" by the cantonnier was essentially maintenance. The following three tables show the cost of resurfacing

[1] Cf. Reports from First International Road Congress, Paris, 1908: No. 26, by Arnaud; No. 22, by Blumhardt; No. 23, by Fuchs; No. 28, by Herpin; No. 29, by Lelievre; and No. 25, by Verstraete.

work in the Duchy of Baden, in Germany, during the period from 1900 to 1907.

TABLE III.—*Results of general resurfacing of six roads in the valley of the Black Forest, Germany.*[1]

Name of road.	Average life of road (years).	Length (miles).	Tons of stone per mile.	Tons of stone per mile per year.	Cost per ton.	Cost of laying stone per ton.	Total cost per mile per year, metal and laying.	Kind of stone.
St. Blasien-Albbruck	4.0	14.62	984	247	$0.997	$0.473	$363	Porphyry, gneiss, and diorite.
Krozingen-Gare d'Urzenfeld	4.2	3.77	875	210	1.330	.442	373	Porphyry.
Gutach-Freudenstadt	4.3	11.50	821	193	1.112	.425	297	Granite.
Oppenau-Kniebs	4.6	3.63	889	195	.941	.391	263	Porphyry.
Achern-Freudenstadt	4.0	6.40	889	222	.847	.400	279	Do.
Rastatt-Freudenstadt	4.0	13.13	923	233	1.402	.344	410	Do.
Averages	4.3	[2] 53.05	908	[3] 211	1.220	.410	344	

[1] Cf. Reports First International Road Congress, Paris, 1908, No. 23, by R. Fuchs.
[2] Total mileage of roads.
[3] Equivalent to 0.024 ton per square yard per year for a 15-foot road.

TABLE IV.—*Results of general resurfacing of the roads of Baden, Germany.*[1]

[Classified according to the kind of stone.]

Kind of stone.	Mean life of metal (in years).	Length of road (in miles).	Tons of stone per mile.	Tons of stone per mile per year.	Cost per ton.	Cost of laying stone (per ton).	Total cost per mile per year, metal and laying.
Porphyry	4.58	128.0	957	208	$1.233	$0.423	$343
Calcareous	5.35	5.0	881	162	.775	.314	176
Wackite	4.98	28.0	915	182	1.070	.446	276
Granite, gneiss, and argillaceous schist	4.26	23.9	835	196	1.065	.441	296
Diorite and hornblende	3.27	3.2	864	264	1.235	.388	429
Basalt and phonolite	4.93	16.6	986	199	1.310	.464	345
Averages	4.66	[2] 204.6	912	[3] 202	1.177	.429	323

[1] Cf. Reports First International Road Congress, Paris, 1908, No. 23, by R. Fuchs.
[2] Total length of all roads (in miles).
[3] Equivalent to 0.0222 ton per square yard per year for a 15-foot road.

TABLE V.—*General resurfacing with porphyry (classified by duration of the metaling), Baden, Germany, 1906–7.*[1]

Life of surfacing (in years).	Length of road (in miles).	Tons of stone per mile.	Tons of stone per mile per year.	Cost per ton.	Cost of laying stone (per ton).	Total cost per mile per year, metal and laying.
2	1.20	901	451	$1.15	$0.426	$711
3	16.78	1,011	337	1.28	.377	562
4	28.31	992	248	1.18	.407	395
5	37.86	939	188	1.17	.411	295
6	27.91	921	154	1.26	.482	265
7	11.98	949	136	1.31	.453	242
8	3.78	955	119	1.45	.449	227
[2] 4.58	[3] 128.0	[2] 957	[4] 208	[2] 1.23	[2] .423	[2] 343

[1] Cf. Reports First International Road Congress, Paris, 1908, No. 23, by R. Fuchs.
[2] Average.
[3] Total length of road (in miles).
[4] Average amount equivalent to 0.0213 ton per square yard per year for a 15-foot road.

Additional resurfacing costs for ordinary macadam are shown in Table VI.

TABLE VI.—*Construction and maintenance cost data on 18 sections of Maryland roads.*[1]

Section No.	Material used.	Time when used.	Area (square yards).	Resurfacing macadam—cost per square yard.	Cost of pitching, including chipping.	Maintenance to Jan. 1, 1911—cost per square yard.	Total cost of treatment to Jan. 1, 1911, per square yard.	Total cost of road surface to Jan. 1, 1911, per square yard.
1	Texaco	July and August, 1909.	11,226	$0.337	$0.327	$0.088	$0.415	$0.752
2	Gulf	August and September, 1909.	1,936	.339	.434	.080	.514	.853
3	Texas	September, 1909	1,243	.336	.418	.187	.605	.941
4	Fairfield	do	1,173	.337	.449	.081	.530	.867
5	U. G. I	do	1,712	.339	.344	.081	.425	.764
6	Warren	September and October, 1909.	1,908	.333	.606	.079	.685	1.018
7	Tarvia	October, 1909	1,909	.337	.618	.082	.700	1.037
8	Tarite	do	1,816	.336	.605	.080	.685	1.021
9	U. G. I	November, 1909	1,264	.340	.454	.091	.545	.885
19	S. O	do	128	.241	.174	.087	.261	[2] .502
20	U. G. I	October, 1909	1,294	.230	.408	.088	.496	.726
21	Texas	do	694	.228	.551	.088	.639	.867
22	Gulf	do	977	.229	.405	.082	.487	.716
23	Warren	do	845	.224	.691	.082	.773	.997
24	U. G. I	September, 1909	2,246	.229	.257	.081	.338	.567
25	Fairfield	do	1,532	.228	.353	.057	.410	.638
26, 27	Local and U. G. I.	August, 1909	5,207	.216	.303	.057	.360	.576
	Averages		[3] 37,110	.299	.402	.081	.483	.782

[1] Proceedings of American Society of Civil Engineers, vol. 37, March, 1911, p. 370. The Use of Bituminous Materials by Penetrative Methods, by W. W. Crosby.
[2] Material gratis.
[3] Total area in square yards.

Ordinary macadam resurfacing costs in Allegheny County, Pa., in 1911, averaged 38.4 cents per square yard on 19.4 miles. On about 100 miles previously resurfaced with 4 inches of broken stone the cost was 44 cents per square yard.

MAINTENANCE OF ORDINARY MACADAM ROADS.

Under the system of periodical resurfacing at intervals of six years and more, the continuous maintenance of an ordinary or water-bound macadam road must take care of small patching and fill up ruts and hollows. Frequently a new macadam road shows some raveling, and it is necessary to remove the scattering, loose stones, which are stacked for future use. The primary object of macadam surface maintenance under the periodic repair system is, therefore, to prevent incipient ruts from becoming deeper, to fill up holes which hold water, to stop raveling, and to clean the road of organic matter, mud, and dust. Where a road shows frost action in the spring, rolling with a steam roller produces excellent results. Sometimes there is a tendency for ordinary macadam roads which are exposed to wind action to ravel during the dry summer months.

Such raveling occurs from loss of fine bonding material and has been combated with more or less success, particularly in Massachusetts, by the application of a coat of coarse sand. The application of sand is made along the center portion of the road and is soon spread by travel over the width of macadam. The coarse screenings which work toward the edges of a road are sometimes swept back to the center with push brooms. A supply of No. 2 stone or stone of the size in the wearing course should always be placed along the roadside in stacks of sufficient size to prevent scattering and loss. Plate I, figure 1, shows stone stacks along an ordinary macadam road in Tasmania.

It is necessary, in addition to the maintenance of the macadam surface itself, to clean the gutters, catch basins, and culverts which constitute the drainage features of the road. The road shoulders must be kept pared and free from weeds, and small gullies on the shoulders and embankments must be repaired before they become too large. Guard rails must be repaired and painted and the general neatness of the roadway preserved. In Allegheny County, Pa., the road patrolman also whitewashes culvert ends, sewer heads, etc., as a protection to travel. The cost of such maintenance for a number of years averaged approximately $100 per mile in the State of Massachusetts, where the macadam roadways are built 15 feet wide and a large percentage of them are surfaced with trap rock which had been bonded with screenings of the same material. The Massachusetts authorities estimate that the expense was equally divided between work on the macadam surface itself and the care of the roadway. The cost of patrolling the ordinary macadam roads in New York State, where men are in charge of sections averaging 5 miles and supply hand tools and a horse with a cart, is expected to be about $125 per mile.[1] This cost does not, however, include material, which is furnished by the State. The use of some form of bituminous material in macadam road construction and in resurfacing operations upon old roads has now become so well established that the problem of macadam road maintenance has necessarily changed to a problem of maintenance of roads on which bituminous material has been used. A further discussion of macadam road maintenance is therefore given under the subject of bituminous-macadam resurfacing and surface treatment.

It is clear from the above analysis of the cost of general resurfacing and of continuous maintenance of ordinary or water-bound macadam roads that the annual charge for all repairs and maintenance of such roads has been about $525 per mile per year for a 15-foot road, or about $35 per foot of width of macadam surface per mile. This charge allows from $100 to $125 for annual maintenance by a patrol and an annual charge of from 4.54 cents to 4.83 cents per square yard for resurfacing at necessary periods. The annual charge per mile is

[1] Cf. footnote p. 61.

rated as a charge against the hardened way itself for purposes of uniformity. It is quite probable that in many instances the cost of maintaining the roadway or roadside outside of the macadamized portion will be less than $50 per mile, particularly as the continuation of good maintenance brings the whole road into better control from year to year. It must be understood that this figure is an average figure and varies with the intensity of travel, as well as with climate, the cost of road material, and the price of labor. It is furthermore a figure for standard maintenance and repair and insures the life of the road indefinitely for similar traffic without any additional cost. Future study should aim to determine in advance of construction the most economical width of macadam surfaces for maintenance under the expected increase of traffic which follows improved roads and increases from year to year.

ACTION OF AUTOMOBILES.

During the years from 1906 to 1913 there has been a great increase of automobile travel upon first-class country roads. It is now demonstrated beyond doubt that an ordinary water-bound macadam can not successfully withstand the action of a considerable amount of automobile traffic.[1] A macadam surface is dependent upon the preservation of its bond. The binding of the road stones is partly due to the keyed position of the stone after rolling and partly due to the presence of the "fines" or stone screenings which completely fill the voids and by their cementing action render this road crust in a sense monolithic. This cementing quality of road stone screenings varies with the stone and reaches its maximum when wet.[2] Under the wear of iron-tired vehicles drawn by horses there is a constant abrasion of road stones which renews the binding material in sufficient amount to maintain an effective bond. The motion of a horse-drawn vehicle, moreover, produces only sufficient shearing force under the tread of the wheel to allow rolling to take place; so that even with heavily loaded vehicles, owing to the small axle friction, the tangential or shearing force upon the road is not immediately destructive. The effort necessary for traction of the horse-drawn vehicle is dependent upon the application of the horse's hoof to the road. The horseshoe, therefore, causes some displacement of the road surface. The shearing force caused by the horseshoe is seldom sufficient, however, to disturb a well-bonded road to a harmful extent.

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[1] According to figures from the Massachusetts Highway Commission, water-bound macadam will withstand from 100 to 150 light teams, from 175 to 200 heavy one-horse teams, from 60 to 80 two-horse teams, and not more than 75 automobiles per day. W. S. Sohier, chairman, "Traffic Census as a Preliminary to Road Improvement," in Good Roads, Jan. 4, 1913.

[2] No available reagent has yet been found which will artificially increase the cementing value of natural stone dust to the requisite degree for modern conditions.

The harmful action of automobiles has been a subject of much discussion, and for a considerable time it was thought that a certain vacuum effect occurred immediately under the tread of the rubber tire which sucked the fine binding material from the roadstones. As the automobile wheel passed, it was noticed that more or less dust was raised, and that usually a considerable amount of binding material was carried away from the roadway. It is now known that the shearing force against the direction of the motion of the automobile is the primary source of trouble. This shearing force is developed at the contact of the rear tire with the road surface, and may easily attain 400 pounds for each rear wheel under unfavorable conditions.[1] The circular section of the automobile tire necessitates deformation when it is in contact with the road and causes secondary shearing at the surface. A partial vacuum does occur under the rear quadrant of the rapidly moving wheels and behind the body of the automobile itself. Eddy currents of air are, therefore, established which increase in strength with the speed and size of the machine and which cause the finely pulverized road material to leave the surface and pass off the road in considerable volume. The automobile tire itself produces little, if any, grinding effect on the roadstone, and can not, therefore, replace the "fines" which have been removed. When irregularities, such as lumps and depressions or loose stone, exist on a road, the pounding effect of automobiles at high speeds is very harmful to the road and the machine, and increases as the square of the speed. The centrifugal force at times has an effect in tending to push the surface material to the outside and destroy the crown of the road, and it also varies with the square of the speed.

With the combined shearing effect under the rear wheels and the loss of binder, a dry macadam road necessarily disintegrates. When the road stones in the surface have become even slightly loosened, the harmful action of the automobile is enormously accelerated, and when the surface has once become generally loosened the normal pressure due to the weight of the automobile comes into play to increase the ruts and eventually to destroy the top course completely and even to cut through to the foundation. The harmful effect of automobiles at high speed is, therefore, undoubtedly greater than at low speed. The point at which increased speed becomes a menace depends partly on the road condition. Speed on a perfectly smooth and homogeneous surface such as asphalt or concrete in itself does no damage. Change in speed or acceleration is directly harmful because the shear increases under the driving wheels.

When once the full effect of automobile travel in increasing volume became recognized, it was apparent that some artificial bond or

[1] See Reports of the First International Road Congress, Paris, 1908: No. 77, M. Malieu, and No. 78, M. A. Petot.

binder was required. The bituminous material adopted for such purposes by highway engineers may be described as a viscous adhesive liquid with cementing and waterproofing properties. There is a great variety of such liquids, which are spoken of in this bulletin as bituminous binders because they all contain more or less of the substance known as bitumen.[1]

The selection and management of bituminous material requires skill and experience. Final standard specifications for the material itself have not yet been developed, nor is it likely that any suitable standard can be evolved which will be sufficient for all conditions. There are certain accepted chemical and physical tests which are necessary for good materials, but these tests are not always sufficient to insure results in practice. The selection of bituminous material is very dependent on local conditions.

BITUMINOUS RESURFACING.

Although the repair or resurfacing of ordinary macadam roads with a bituminous binder is comparatively recent, certain important facts are now sufficiently well defined. There still exists some variation in the character of bituminous material used and in the application of such materials.

It has been found expedient in general, where roads are much worn, first to scarify or loosen the old macadam and then to add sufficient new stone to restore a true crown. Earth shoulders are carefully preserved along the edges of the foundation course. Either of two general methods of resurfacing may then be employed—the mixing method or the penetration method.

Mixing method.—By the mixing method, No. 2 clean hot stone varying in size usually from 1½ inches to ¾ inch is thoroughly mixed with some form of hot bituminous material. From 16 to 25 gallons of bitumen is usually necessary to the cubic yard of stone. The mixing may be done either by hand on a mixing board or in some form of mixing machine. When the stone becomes thoroughly coated with the bituminous material, it is at once spread to the required depth upon the old reshaped surface, which has been thoroughly rolled. Spreading is usually done by hand from dumping boards. Sometimes before rolling the bituminous-mixed course a coat of clean sharp screenings, fine gravel, or coarse sharp sand is spread to fill the voids and prevent the roller from adhering. When

[1] See Office of Public Roads Bulletin No. 34, "Dust Preventives"; Bulletin No. 38, "Methods for the Examination of Bituminous Road Materials"; Circulars Nos. 47, 89, 90, 92, 94, and 98, Progress Reports of Experiments in Dust Preventives and Road Preservation; Circular No. 96, "Naphthalene in Road Tars"; Circular No. 97, "Coke Oven Tars of the United States"; and Extract No. 538 from the Yearbook of the Department of Agriculture, "Bituminous Dust Preventives and Road Binders." Copies of these publications may be obtained by applying to the Secretary of Agriculture, Washington, D. C.

the course of mixed material has been thoroughly compacted and the "fines" worked into the voids, all loose fine material is removed from the entire road surface by vigorous sweeping with stiff brooms until a bare mosaic surface appears entirely free from dust or loose screenings. Care must be used in cleaning to prevent loosening of the stone. The "fines" removed by sweeping are saved to be applied again to the road if they are not too dusty. A paint or surface coat of bituminous material is applied usually at the rate of about one-half gallon to the square yard, and a second course of clean stone screenings is spread upon this thin layer of bituminous material. In resurfacing by the mixing method, it is customary to apply a layer approximately 3 inches thick of loose bituminous-coated stone. The amount of consolidation will depend somewhat upon the weight of the roller used. It is not necessary to finish bituminous-bound macadam roads with as high a crown as ordinary water-bound macadam roads demand. A crown of from one-fourth to one-half inch to the foot is in current use. Since the finished surface is more nearly waterproof, there is less chance that surface water will penetrate, and a low crown tends to distribute traffic.

Penetration method.—The penetration method of bituminous resurfacing work is carried out by first placing the second course of No. 2 stone to the required depth; then the roller is used nearly to complete the consolidation. Hot or cold bituminous material is applied at the rate of about $1\frac{1}{2}$ gallons to the square yard. The application is made either by hand pouring pots with flanged nozzles, by a hose leading from a tank wagon, or by some of the various machine spreaders. Essential features of the application are to make it uniform and to avoid having dense or dirty spots in the stone.

After the application of bituminous binder, stone screenings free from dust are applied and the rolling is completed exactly as in the mixing method.

In Table VII is given the cost of bituminous resurfacing operations upon a number of roads in New York State. The work was done under contracts let by the State department of highways.

TABLE VII.—*Resurfacing costs in New York State (bituminous macadam) 1909–10.*

Road No.	Year when built.	Resurfaced. Width (feet).	Resurfaced. Miles.	Age (years).	Cost. Per mile.	Cost. Per square yard (cents).	Cost. Per square yard per year (cents).	Total cost of job.
3,71	1900	14	6.250	10	$6,624	80.6	8.06	$41,400
181	1904	12	3.850	6	5,105	72.5	12.09	19,654
203, 204, 205	1904	12	3.634	6	5,024	70.1	11.69	18,257
383	1906	16	1.770	4	5,646	60.1	15.04	9,993
81	1902	16	4.060	8	5,143	54.8	6.85	20,883
6	1899	16	1.690	11	4,621	49.2	4.47	7,809
272	1906	16	1.210	4	5,410	57.6	14.41	6,546
591	1906	12	3.500	4	4,947	70.3	17.56	17,313
143, 148, 149	1903	12	6.020	7	6,095	86.5	12.36	36,690
20, 35, 50	1901	14	8.370	9	6,974	84.9	9.44	58,371
51, 144, 150	1902	13	11.175	8	6,864	90.0	11.25	76,700
37, 38	1902	12	8.873	8	5,643	80.1	10.01	50,074
116	1902	14	2.481	8	5,211	63.4	7.93	12,927
104	1902	16	1.250	8	5,937	63.2	7.91	7,420
108	1902	15	1.760	8	5,961	67.7	8.46	10,491
119	1902	16	3.760	8	6,828	72.7	9.09	25,674
92	1902	16	1.740	8	5,975	63.7	7.96	10,398
58	1901	12	3.520	9	4,757	67.6	7.51	16,742
59	1901	16	2.430	9	5,404	58.6	6.51	13,132
25	1900	15	2.547	10	6,039	68.6	6.86	15,381
32	1901	12	1.860	9	5,889	83.6	9.29	10,953
314	1906	16	4.370	4	4,409	47.0	11.74	19,268
146	1903	14	5.09	6	4,808	58.5	9.76	27,018
133	1903	14	0.96	6	6,627	80.7	13.45	6,361
182	1904	12	2.76	5	4,293	61.0	12.20	11,850
181, 186	1904	12	3.91	5	4,172	59.3	11.85	16,313
56, 137, 138	1902	16	8.20	7	4,339	46.2	6.60	35,582
39, 59	1901	16	3.70	8	6,236	66.4	8.30	21,752
97	1902	12	2.40	7	6,272	89.1	12.73	23,083
58	1901	12	2.50	8	5,690	80.8	10.10	15,053
32, 108	1902	14	1.51	7	5,817	70.8	10.12	8,783
36, 217	1902	13	2.57	7	5,061	66.4	9.48	13,007
Averages			[1] 125.336	7.39	5,716	72.4	9.83	[2] 716,394

[1] Total mileage resurfaced; equivalent to 989,239 square yards. [2] Total expenditure on all roads.

Additional costs of bituminous resurfacing are shown in Table VI and in Table VIII.

TABLE VIII.—*Construction cost data on eight sections of Maryland roads.*[1]

Section No.	Material used.	Time when used.	Area (square yards).	Cost for resurfacing macadam (per square yard).	Cost of pitching, including chipping (per square yard).	Total cost of road surface (per square yard).
10	U. G. I	May and June, 1910	3,532	$0.397	$0.242	$0.639
11	Texas	June, 1910	5,981	.397	.264	.661
11-A	Mixed tar	do	1,261	.397	.262	.659
12	Headley	June and July, 1910	4,685	.397	.327	.724
13	B. A. P	July and August, 1910	4,203	.397	.325	.722
14	Fairfield	Aug. and Sept., 1910	3,184	.397	.292	.689
15	Fairfield Antidust	October, 1910	5,808	.397	.084	.481
16	U. G. I. Antidust	Sept. and Oct., 1910	1,100	.397	.140	.537
	Averages		[2] 29,754	.397	.243	.640

[1] Proceedings of American Society of Civil Engineers, vol. 37, March, 1911, p. 370, "The Use of Bituminous Materials by Penetration Method," by W. W. Crosby.
[2] Total number of square yards.

During 1911 the bituminous reconstruction of 32.55 miles in Allegheny County, Pa., cost on an average of 92.3 cents per square yard. The subdivided cost per square yard of reconstructing 14,764 square yards by the penetration method in Baltimore, Md., is reported [1] as follows:

TABLE IX.—*Cost per square yard of road construction in Baltimore, Md.*

	Cost (cents).
Labor	24.82
Stone	27.40
Rolling	4.84
Binder	13.74
Coal	.95
Hauling binder	.41
Incidentals, including supplies and repairs to plant	.79
Total	72.95

The quantity of bituminous material was 1.9 gallons per square yard.

The detailed cost of bituminous resurfacing at Chicopee, Mass., in 1912, with a 2-inch layer by the mixing method is reported by the State highway commission as follows:

TABLE X.—*Cost per square yard of 2-inch bituminous resurfacing by mixing method at Chicopee, Mass.*

Bitumen at the rate of 1.54 gallons	$0.10
Trap rock, pea stone covering, at the rate of 0.027 ton per square yard	.07
Heating, mixing, and applying	.20
Trap-rock broken stone, at the rate of 0.115 ton per square yard	.30
Total	.67

Considerable work, in the nature of bituminous resurfacing, has been done by the Office of Public Roads, with the cooperation of several localities. In general, the roads treated were not excessively worn and the cost of the work, which is given in the table below (Table XI), does not include preparation of the foundation course except where specified. The weighted average cost of stone in place was $1.35 per ton, which is somewhat low, and no cost of supervision is included.

[1] Proceedings American Society of Civil Engineers, Vol. XXXVII, pp. 373 to 375, "Road Construction and Maintenance," by R. K. Compton.

TABLE XI.—*Bituminous surfacing by Office of Public Roads.*

Location of work.	Kind of material.	Year when built.	Freight and miscellaneous (per square yard).	Length surfaced (feet).	Area (square yards).	Stone.		Bituminous material.						Total cost (per square yard).	Total cost of job.
						Tons (per square yard).	Cost of stone in place (per ton).	Gallons (per square yard).	Cost (per gallon).	Heating (per square yard).	Hauling (per square yard).	Applying and mixing (per square yard).	Rolling (per square yard).		
										Cents.	*Cents.*	*Cents.*	*Cents.*	*Cents.*	
Westminster, Md	Water-gas tar and oil	1910	[1] $0.067	5,650	20,500	0.155	$1.64	2.3	$0.070	0.88	0.47	0.95	0.17	[1] 56.6	$11,618.25
El Paso, Tex	Asphalt—penetration method	1909	....	....	23,470	.145	[2] 1.45	1.8	.090	....	[2] 6.55	....	....	44.08	10,344.20
Bowling Green, Ky	Rock asphalt	1907	[3] .057	385	770	.154	.94	[4] 8.2	[5] 5.82	....	....	1.44	2.18	[3] 47.63	366.79
Newton, Mass. (mixing method):															
No. 1	Asphaltic preparation	1908	....	222	567	.158	.69	.54	.13	(6)	20.23	7.87	(7)	46.92	266.04
No. 2	do	1908	....	499	1,226	.158	.69	.54	.13	(6)	20.23	7.87	(7)	46.92	578.05
No. 3	do	1908	....	479	1,064	.158	.69	.54	.13	(6)	20.23	7.87	(7)	46.92	499.23
No. 5	Asphaltic preparation with flush coat.	1908	....	98	223	.158	.69	1.12	.13	(6)	23.59	7.87	(7)	64.04	142.81
No. 7	Asphaltic preparation	1908	....	232	618	.158	.69	.71	.13	(6)	20.23	7.87	(7)	48.16	298.11
No. 10	Water and coal-gas tar	1908	....	326	869	.160	.69	.99	.08	(6)	23.10	12.18	(7)	46.55	183.70
Ithaca, N. Y. (penetration method):															
No. 1	Refined coal tar	1909	.050	300	620	.179	1.01	2.02	.065	2.02	2.84	(7)	.92	45.92	284.70
No. 5	Refined semiasphaltic oil	1909	.040	300	533	.179	1.01	1.50	.115	1.50	2.92	(7)	.92	49.32	262.88
No. 6	Semisolid refined semiasphaltic oil.	1909	.034	300	533	.179	1.01	1.64	.07	1.64	3.19	(7)	.92	43.32	230.90
No. 7	Refined water-gas tar	1909	.046	300	533	.179	1.01	1.88	.07	1.88	3.65	(7)	.92	46.95	250.24
No. 8	Refined semiasphaltic oil	1909	.038	300	533	.179	1.01	2.06	.07	2.06	4.01	(7)	.92	52.30	278.76
Ithaca, N. Y. (mixing method):															
No. 2	Refined coal tar	1909	.074	300	622	.179	1.01	1.36	.08½	.44	2.65	10.32	.92	56.02	348.44
No. 4	Artificial oil asphalt	1909	.136	275	489	.179	1.01	.92	.10	....	1.79	10.32	.92	56.62	286.65
No. 12	do	1909	.072	260	463	.179	.89	1.90	.07½	.98	3.70	18.59	.92	60.89	281.92
Ithaca, N. Y. (penetration method):															
No. 15	Oil asphalt	1910	.037	300	533	.181	1.14	1.50	.07½	1.85	1.90	(7)	5.01	49.73	265.06
No. 16A	Refined asphaltic preparation	1910	.053	106	308	.242	1.17	1.60	.11½	6.76	1.01	(7)	5.01	69.36	213.63
No. 16B	do	1910	.035	140	200	.242	1.17	.80	.11½	3.38	.51	(7)	5.01	54.43	141.5[illegible]

[1] Cost of preparing subgrade, 6.7 cents per square yard, included in final cost.
[2] Includes cost of heating, laying, and rolling.
[3] Cost of preparing subgrade, 5.7 cents per square yard, included in final cost.
[4] Pounds per square yard.
[5] Dollars per ton, including cost of hauling.
[6] Included in cost of mixing.
[7] Included in cost of hauling.

Table XI.—*Bituminous surfacing by Office of Public Roads*—Continued.

Location of work.	Kind of material	Year when built.	Freight and miscellaneous (per square yard).	Length surfaced (feet).	Area (square yards).	Stone.		Bituminous material.						Total cost (per square yard).	To al cost of job
						Tons (per square yard).	Cost of stone in place (per ton).	Gallons (per square yard).	Cost (per gallon).	Heating (per square yard).	Hauling (per square yard).	Applying and mixing (per square yard).	Rolling (per square yard).		
Ithaca, N. Y. (mixing method):										*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Cents.*	
No. 17	Oil asphalt	1910	$0.045	300	533	0.189	$0.83	1.43	$0.11½	2.13	3.37	29.6	5.01	82.18	$438.02
No. 18A	Refined semiasphaltic oil	1910	.036	206	366	.181	.83	1.38	.07	2.17	4.83	27.0	5.01	72.49	265.32
No. 19A	Refined water-gas tar	1910	.044	130	231	.189	.83	1.43	.07	1.17	3.83	17.3	5.01	62.84	145.16
No. 19B	do	1910	.036	170	302	.181	.83	1.01	.07	....	4.38	19.8	5.01	60.34	182.23
No. 20	Oil asphalt	1910	.055	296	526	.206	.83	1.53	.10	1.47	3.43	18.4	5.01	72.26	380.09
Knoxville, Tenn. (penetration method):															
No. 1	Refined coal tar	1910	.023	217	482	.188	.85	1.99	.11	....	.36	2.78	1.27	46.89	226.01
No. 2	Refined tar preparation	1910	.061	590	1,311	.188	.85	1.71	.06	....	.19	3.24	.80	40.83	535.28
No. 3	Oil asphalt	1910	.023	173	405	.188	.85	2.19	.07⅓	....	....	2.96	.91	40.56	164.27
Averages	....	....	....	....	[1] 58,890	....	....	....	....	....	....	....	....	50.05	[2] 29,478.26

[1] Total area in square yards.

[2] Total cost of all roads.

SURFACE TREATMENT.

The term "surface treatment" is used in this bulletin to designate primarily that treatment with bituminous material which is applied to a water-bound or ordinary macadam road, or which is subsequently applied to a macadam road constructed or resurfaced with bituminous material and which is intended to supply a wearing coat to the road and to prevent the formation of dust. Essential distinguishing features of surface treatment are, then, the application of a course of screenings or broken stone or equivalent "fines," such as clean small gravel or coarse sharp sand, and the use of heavier bituminous material.

The entire process of surface treatment has become fairly well defined. The principal operations are as follows:

(*a*) Cleaning the old macadam road surface thoroughly with a mechanical sweeper or hand brooms, so that no fine material or dust remains.

(*b*) Restoring an even smooth surface by placing No. 2 stone or clean screenings and bituminous material in hollows and ruts.

(*c*) Applying a uniform coat of bituminous material over the entire macadam surface.

(*d*) Covering the bituminous material with stone screenings from which the dust has been removed, or with equivalent material, such as clean fine gravel or sharp coarse sand.

(*e*) Rolling with a light roller or, after a sufficient interval, opening the road to travel without rolling.

There are a number of modifications and variations of the process of surface treatment, as outlined above.[1] The object of such treatment is to supply a wearing coat more or less resilient, and to prevent the formation of dust, the loss of binding material, and the consequent disintegration of the road surface.

It has been observed that where a perfect surface is *continuously maintained* upon a road the harmful action of automobiles is almost completely stopped. The bituminous material incorporated with broken stone screenings forms a protective coating, "carpet," or "enamel" which prevents the *beginning* of ravel due to shear and the loss of binding material under the action of automobiles.

Even the smallest amount of dust remaining on an old macadam surface when the bituminous coat is applied may prevent the proper adhesion and cause subsequent flaking or peeling. Care must be used, however, in sweeping not to disturb the larger stones in the old surface, and for this reason soft brooms may be used to complete the sweeping. Machine sweepers are being used in increasing numbers and do their work more cheaply, but some hand sweeping is usually needed for a perfect job.

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[1] See Office of Public Roads Bulletin No. 34, "Dust Preventives," for further detail as to bituminous material and its use.

Ruts or depressions which occur in a road surface may be picked out clean, coated with bituminous material, and then filled with clean stone previously mixed with bituminous material, or the stone may be covered when it is in place. It is necessary that the road surface present an even, smooth condition before the bituminous material is spread upon it. All hollows become points of wear and collect water, which tends to disintegrate the bituminous material.

It is very desirable for a coat of bituminous material to penetrate the surface of the road to some extent, and for this reason the more perfectly the old road mosaic is exposed by sweeping without loosening the stone the better the results will be. The bituminous material may be applied hot or cold to a dry road, as described above. Push brooms are also used to work the bituminous material over the road surface.

A number of instances are on record where excellent results have followed the application of a bituminous coat to roads which have been previously soaked with water and allowed partially to dry over night. Apparently the resulting moisture induces capillarity and offers a better chance for the bituminous material to take hold or penetrate, notwithstanding the objections to the application of bituminous material to a moist surface.

The presence of dust in the stone screenings is objectionable, as it prevents the intimate adhesion desired. The application of bituminous material should be sufficient to allow some absorption by the road and a sufficient residue to form a mat, "carpet," or "enamel," with the applied "fines" and thus secure a wearing surface thoroughly bonded with the road itself.

There seems sufficient evidence that the application of from 0.3 to 0.5 gallon per square yard of bituminous material is enough, although it may run as high as three-fourths gallon. Excellent results have been obtained where the bituminous material has been spread in two courses. The first course of about one-fourth gallon to the square yard, followed by a coat of screenings, is allowed to stand for a few days and is followed by a second coating of about one-fourth gallon to the square yard and a final coat of screenings. While it is not absolutely necessary to roll the road treated in this way, better results have followed where light rolling has been done. It usually requires from 75 to 125 cubic yards of stone screenings or other "fines" per mile to build a surface coat thoroughly bonded with the road, and from three-eighths to one-half inch in thickness. It is desirable that the bituminous material be well covered by the "fines" and that there be some set or hardening upon cooling. It is necessary to have a sufficient surplus of screenings along the roadside at intervals to take care of all "bleeding" of the surface, as travel upon surface-treated roads tends to bring up the bituminous material from below.

Surface treatment, as above described, has proved an efficient method of maintenance of water-bound or plain macadam roads and is the logical method of maintaining macadam roads which have been built or resurfaced with a bituminous wearing course. The interval of wear of a surface treatment depends in part upon the nature and amount of travel. Indications at present are that the length of service is from one to three years, although longer intervals are on record.

TABLE XII.—*Cost of maintenance on roads oiled in 1909 and not re-treated since (Massachusetts State Highway Commission).*

No.	Year of original expenditure.	Area (square yards).	Length (miles).	Original construction cost per mile.	Cost of oiling in 1909.		
					Total cost.	Cost per square yard.	Cost per mile.
1	1909	7,750	0.880	$9,750.51	$637.50	$0.0823	$724
2	1900	3,090	.351	6,880.43	239.49	.0775	682
3	1897	8,530	.970	8,860.00	618.43	.0725	638
4	1901	10,505	1.000	5,857.51	660.51	.0628	661
5	1899–1904	30,000	3.409	6,551.01	1,745.56	.0581	512
6	1904–5	12,655	1.438	6,032.84	1,256.07	.0992	872
7	1900–1906	51,641	5.868	7,076.01	4,066.17	.0787	693
8	1895–96	25,873	2.940	8,862.60	1,875.79	.0725	638
9	1907–8	10,333	1.174	7,807.04	809.99	.0784	690
Averages	......	[1] 160,377	[2] 18.03	7,519.77	[3] 11,909.51	.0742	660

No.	Cost of patching.					
	1909		1910		1911	
	Per square yard.	Per mile.	Per square yard.	Per mile.	Per square yard.	Per mile.
1	$0.0027	$24.58	$0.0226	$199.21	$0.001	$8.17
2	......	......	......	......	......	......
3	.0009	8.14	.0104	92.11	.0187	165.03
4	.0020	21.20	......	......	.0078	82.63
5	......	......	.0236	207.81	.0229	202.21
6	.0008	7.53	.0054	47.61	.0041	36.44
7	.0008	7.73	.0027	25.27	.0028	24.42
8	.0003	3.36	.0106	93.31	.0072	63.38
9	......	......	.0055	48.89	......	......
Averages	.0007	6.48	.0094	84.59	.0082	73.55

No.	Cost of sanding.						Total cost per square yard.	Total cost per mile.
	1909		1910		1911			
	Per square yard.	Per mile.	Per square yard.	Per mile.	Per square yard.	Per mile.		
1	......	......	$0.0056	$49.72	......	......	$0.1142	$1,005.68
2	......	......	.0065	57 40	......	......	.0840	739.40
3	......	......	.0024	21 53	$0.0026	$23.50	.1075	948.31
4	......	......	......	......	......	......	.0726	764.83
5	......	......	.0016	13.83	......	......	.1062	935.85
6	$0.0039	$34.45	.0243	214.24	......	......	.1377	1,212.27
7	......	......	.0040	35.36	......	......	.0890	785.78
8	......	......	.0062	55.12	.0012	10.61	.0980	864.28
9	......	......	.0025	22.57	.0048	42.53	.0912	803.99
Averages	.0003	2.73	.0052	46.52	.0006	5.76	.0988	879.63

[1] Total area in square yards. [2] Total length in miles. [3] Total cost of all roads oiled in 1909.

Failures of surface treatment have resulted and are probably due to some of the following causes: Insufficient cleaning of the road surface, unsuitable bituminous material, nonuniform application, unsuitable covering material or "fines," excess of dust in the screenings, or unfavorable weather conditions. In all surface treatment operations it is necessary to give careful attention to details.

The preceding table gives a history of the cost on nine ordinary macadam roads in Massachusetts which were given the surface treatment in 1909 and were maintained by small patching during the years 1909, 1910, and 1911. The work was done by the Massachusetts State Highway Commission.

The cost of surface treatment varies with local conditions. The treatments, such as have been described above, should cost from 4 to 12 cents per square yard. The following items (Table XIII) are the subdivided cost figures per square yard for oiling a Massachusetts road in 1910. The conditions were those of an ordinary road in that State. The treatment required one-half gallon of oil per square yard in two applications of one-fourth gallon each. The average haul for oil was 2 miles, and sand for covering was furnished and hauled an average of 2½ miles under contract.

TABLE XIII.—*Cost items per square yard for oiling a Massachusetts road.*

Cleaning and sweeping	$0.0056
Patching old surface	.0016
Cost of oil	.0319
Heating oil	.0031
Delivering oil	.0038
Distributing oil	.0029
Furnishing sand beside road	.0165
Spreading sand	.0073
Watering	.0012
Rolling	.0002
Supervision	.0025
Total	.0766

The detailed cost of two jobs recently reported by the Massachusetts State Highway Commission for 1912 is given below. It will be seen that these costs covered more than is described by the typical resurfacing operations in the text.

Agawam (mixed method).—The road was scarified and the old surplus bitumen was removed, after which the road was reshaped and one-fourth gallon per square yard of standard binder A was applied. This coat was given a light covering of trap pea stone, after which a second one-fourth gallon of oil was applied and covered with pea stone.

TABLE XIV.—*Details of cost per square yard.*

Preparation of road surface, including scarifying, reshaping, etc.	$0.0474
Cost of oil distributed on road, including bitumen, heating, hauling, water, and rolling	.0509
Cost of trap pea stone per square yard, at the rate of 0.035 ton per square yard	.0852
Total per square yard	.1835

Chicopee (penetration).—The old surface was heated with one-half gallon of tar per square yard, which was covered with sand and 0.04 ton of trap broken stone per square yard. A second application of one-fourth gallon of tar per square yard was made and covered with 0.015 ton of trap pea stone per square yard. A third application of one-fourth gallon of tar per square yard was then given and covered with 0.015 ton of trap pea stone per square yard.

TABLE XV.—*Details of cost per square yard.*

Trap broken stone	$0.12
Heating, hauling, and distributing bituminous material	.10
Bituminous material	.065
Trap rock pea stone	.081
Total per square yard	.366

The cost of surface treatment of four roads in Maine is presented in Table XVI.

TABLE XVI.—*Cost of surface treatment of four roads in Maine.*

Name of road.	Kind of road.	Area (square yards).	Year when built.	Cost per square yard.	Maintenance per square yard per year (cents).
Danforth Street, Portland	Plain macadam with refined tar surface.	8,657	1908	$1.330	[1] 3.87
Vaughn Street, Portland	Bituminous macadam, mixing method.	8,807	1909	1.410	[2] 4.764
Cumberland Avenue	Bituminous macadam.	6,398	1910	1.685	[3] 8.631
Kittery trunk line	Plain macadam	13,000	1910	1.220	[4] 7.50
Average		[5] 36,862			5.352

[1] Average 1909, 1910, 1911.
[2] Average 1910, 1911.
[3] Cost of treatment in 1911.
[4] Cost of surface treatment.
[5] Total area in square yards.

Table XVII shows the cost of surface treatment of 1,000 miles of macadam road in the State of New York by the department of highways in 1910.

Table XVII.—*Surface treatment, New York.*

Cost per mile for oiling 1,000 miles of road in 1910:	
Oil	$166.57
Labor, oiling, sweeping, and applying cover	107.22
Material for cover	230.29
Total	504.08

The above cost per mile, assuming a 15-foot road, is equivalent to 5.72 cents per square yard. The bituminous material used was a heavy oil and the screenings were dustless.

In 1906, on the Metropolitan Park roads in Boston, 67,500 square yards of surface were treated for 6.66 cents per square yard. In the following year, 1907, the total cost of small repairs and re-treatments was 3.5 cents. In 1908, re-treatments cost 4.75 cents on one-half the yardage already treated with refined tar; the remainder did not require treatment. The average cost of re-treatments in 1909 and 1910 was 6 cents for each re-treatment, averaging once in two years.[1] Figures on surface treatment by the State Commission of Highways of New York in 1912 show 99,314 square yards treated with hot oil at a cost of 11.75 cents per square yard and 70,108 square yards treated with cold oil at a cost of 6.83 cents per square yard.

Surface treatment of a road subject to considerable motor traffic appears to be the logical and necessary form of repair. For the best results it must be accompanied by continuous strict maintenance. Such maintenance does the small work constantly necessary to keep the surface of the road free from occasional peeling or raveling and the consequent formation of depressions and ruts. Piecemeal bituminous patching involves considerable waste in heating tar and assembling material. It appears that a motor truck supplied with a sprinkling device to resurface with hot bituminous material would be capable not only of doing small patch repairs but of general resurfacing operations when necessary. Experience in Massachusetts and New York and in several counties of other States goes to show that a patrol system under which one man furnishes small tools and a cart with a single horse and spends his entire time upon the road can not be put in effect at less than $125 per mile per year.

Perhaps the most significant fact in connection with surface treatment with bituminous material is the apparent increase of the life of the road. Theoretically, surface treatment supplies a wearing coat or "enamel," which prevents internal wear entirely and supplies an excellent waterproofing for the road. There should be, therefore, no deterioration of the road itself where the surface treatment is effective. This form of road repair has not, however, been practiced for a sufficient length of time to verify this theory. The life of the modern bituminous-bound macadam road is as yet unknown.

[1] Proceedings, American Society of Civil Engineers, March, 1911, pp. 366–367, J. R. Roblin.

FIG. 1.—ROAD IN TASMANIA, SHOWING STACKS OF STONE FOR REPAIRS.

FIG. 2.—DRAINAGE EROSION ON A DRIVEWAY.

FIG. 1.—EARTH ROAD, SHOWING IMPERFECT DRAINAGE.

FIG. 2.—EARTH ROAD IN ALEXANDRIA COUNTY, VA., SHOWING RESULTS OF DRAGGING.

DUST PREVENTION.

There is a form of surface treatment which is largely for the purpose of dust prevention, but which may gradually accumulate a binding layer when material containing an asphaltic base is used. The theory of this treatment is to supply a liquid which binds sufficient dust to prevent it from being raised by air currents from the road surface. The simplest method is to sprinkle the road with water, but this means repeated applications during the summer season, and the expense upon country roads is prohibitive. Various hygroscopic salts have been used, particularly calcium chloride. These salts have the property of absorbing water from the air and they serve, when applied dry or when mixed with water, to hold moisture in the surface of the road and prolong the period of dustlessness. Dry granulated calcium chloride has been used on New York State roads, where it has been applied at the rate of about 1 pound to the square yard, followed by two later applications of three-fourths pound each. The cost is expected to be about $125 per mile if the patrolman does the spreading. The width of application is 10 feet. Dust palliatives are, however, in no sense a structural benefit to the road, although they may serve in a measure to preserve it.

Another form of surface treatment for dust prevention is to sprinkle the road with some form of light oil. This method of road treatment has assumed a variety of forms, which range all the way from a thorough surface treatment intended to build up a road to the lightest spraying of the road surface without addition of any "fines" whatever. It has been found that for certain classes of roads where watering was necessary an annual surface treatment of oil with "fines" combines the results of dust laying and maintenance. There is given below (Table XVIII) the cost of surface treatment of macadam roads in the Washington parks as a substitute for sprinkling with water. The cost of screenings is not included, as that is regarded as a charge for maintenance. In applying this treatment the ruts and hollows are cleaned and filled with coarse clean stone coated with hot asphaltic oil, and then the patch is rammed. The whole road is swept with rattan brooms. The bituminous material—a light asphaltic oil or a low carbon tar—is applied at the rate of from about one-third to one-half gallon to the square yard and the road is then closed to traffic for 48 hours. The cover is clean coarse sand or screenings free from dust. The road is finally rolled. The application lasts one year, and it is expected that the amount of oil needed will decrease in the future to from one-fourth to one-sixth gallon per square yard. The spreading was done with a sprinkling wagon fitted with an oil distributing attachment and a squeegee fitted behind. The material was worked with stiff brooms.

TABLE XVIII.—*Cost of surface treatment of the macadam roads in the parks of Washington, D. C., July 1, 1910, to June 30, 1911.*[1]

No. of road.	Kind of material.	Quantity (gallons).	Area of road (square yards).	Length of road (feet).	Square yards treated (per gallon).	Cost of oil and applying per square yard (cents).
1	Oil	2,300	7,500	1,300	3.26	[2] 2.8
2	...do	4,000	19,000	3,500	4.75	[3] 2.2
3	...do	1,000	3,400	650	3.40	[3] 2.7
4	...do	700	8,600	2,300	12.23	[3] 1.2
5	...do	5,000	25,000	5,000	5.00	[3] 2.1
6	...do	10,600	43,560	9,000	4.11	[3] 2.2
7	...do	3,400	19,450	3,800	5.72	[3] 1.9
8	...do	350	4,000	1,200	11.43	[3] 1.3
9	...do	1,000	1,680	700	1.68	[4] 4.6
10	Tar	6,000	11,400	3,500	1.90	[4] 4.4
11	...do	650	1,500	1,600	2.30	[4] 3.8
12	...do	1,600	3,560	1,600	2.23	[4] 3.8
13	...do	2,580	7,740	2,800	3.00	[4] 3.1
14	...do	2,400	8,100	2,100	3.39	[4] 2.8
15	...do	875	2,000	700	2.38	[4] 3.8
Total		43,455	166,490	38,650	[5] 3.83	[6] 2.5

[1] From a paper presented by Col. Spencer Cosby, United States Army, to the American Association for the Advancement of Science, January, 1912.
[2] Second and third applications.
[3] Second application.
[4] First application.
[5] Average number of square yards treated per gallon.
[6] Average cost of oil and applying per square yard.

In this work the following cost items are also of interest: Cost of labor per square yard, 0.8 cent; cost of oil per gallon, 6.5 cents; cost of tar per gallon, 6.8 cents; and average cost in past years of watering roads, per square yard, 3.2 cents.

With screenings included at the rate of 1 cubic yard, costing $1.70, for each 100 square yards and necessary labor at 0.8 cent per square yard, the cost of the surface treatment presented in the above table would be 5 cents per square yard. This system affords strict maintenance to the lightly traveled roads in question and apparently approximates absolute maintenance.

The following table shows the average cost per square yard of applying dust preventives in the District of Columbia for the year ending June 30, 1911:

TABLE XIX.—*Average cost per square yard of applying dust preventives in the District of Columbia in the year ending June 30, 1911.*

Location of work.	Oil (from one-fourth to one-half gallon per square yard).	Labor for hauling, applying, cleaning, and protecting road.	Screenings or sand.	Total cost.
Ridge Road, Rock Creek Park (liquid asphalt)	$0.037	$0.010	$0.003	$0.050
Twentieth Street, etc. (asphaltoilene; contract)	[1] .050	.010	.008	.068
Connecticut Avenue (Standard No. 6; light oils)	.012	.018	.004	.034
Rock Creek Church Road (one application of Texas road oil No. 2)[2]	.011	.002	.000	.013
Wisconsin Avenue (15 applications per season of emulsified oil)	.022	.012	.000	.034
Military Road (tarvia B)	.038	.021	.003	.062
Various streets (8 applications of calcium chloride)	.030	.011	.000	.041

[1] Applied by contract, hauling included in price of oil.
[2] This work was done in the fiscal year 1912 and is used for comparison. Two or three applications per season would be needed.

During the season of 1911 oiling in Rhode Island with a light semi-asphaltic oil cost $96 per mile for a 14-foot road, or 1.17 cents per square yard. The application was about one-eighth gallon per square yard and was made under pressure with an auto tank truck. The cost of filling holes with stone and top dressing is not included in the oiling price. The State spent $31,000 for oiling and $71,967 for filling holes with crushed stone and top dressing.

In Allegheny County, Pa., for five years (1907 to 1911), light asphalt-road oil has been used as a dust layer. Between 300,000 and 400,000 gallons have been used each year, and the distribution is made from tank wagons and distributors owned by the county. The county is subdivided into four sections, each in charge of an assistant superintendent, and the work of oiling is done with the county force. The mileage of completed roads was about 400 in 1911. The total cost of applying oil is about 2¼ cents per square yard, and no screenings or other "fines" are used.

EARTH ROADS.

At the beginning of the year 1913, 90 per cent, or approximately 2,000,000 miles, of the roads in this country were earth. The repair and proper maintenance of earth roads are therefore of great importance.

REPAIR.

The repair of an earth road has for its object the development of a crowned traveled way, dry and firm under travel, and of proper width. It is desirable that this traveled way be reasonably straight and not too steep. It is known that it is first necessary to protect the roadway from water, and therefore repair operations begin with drainage. Pure sand roads are an exception to this principle.

Drainage.—Drainage intercepts water which would otherwise reach the road and removes water which accumulates on the road. A broad shallow ditch on each side of the traveled way is required for drainage. Such ditches must have ample outlets into natural drainage channels, and all culverts to carry water across the road should be kept free from obstructions. When the road soil is clay, the side ditches should be deepened and the traveled way somewhat raised to increase the protection against water. Figures 4 and 5 show good standard earth road sections to provide drainage. It is clear that with a reasonably firm smooth surface water can not remain on the traveled way.

"Thank-you ma'ams" should not be constructed across the road.[1] Outlets for gutters are needed at every low point and should be large enough to carry off the *worst* flood water quickly. To do this, out-

[1] There seems justification, under extreme conditions, for water breaks, e. g., a long, uniform grade of 10 per cent or greater, with relocation economically impossible, exclusively horse-drawn heavily loaded vehicles, and a considerable watershed. In such instances resting places may serve as water breaks.

lets need to be built with a large factor of safety. In deep cuts and on hillside roads it is frequently necessary to dig a bank ditch above the road on the shoulder of the slope in order to intercept surface water from the hillside. Such ditches should discharge water into natural channels entirely away from the road. The section of a

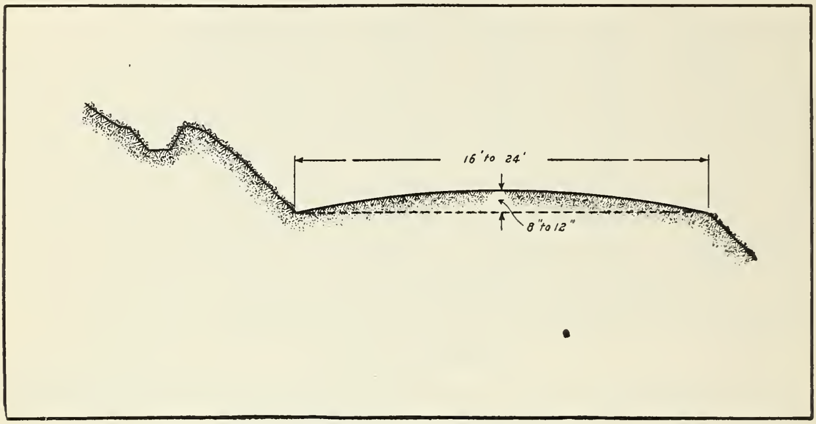

FIG. 4.—Cross section of standard earth road.

road provided with a protection ditch on the bank is shown in figure 4. When culverts of any kind cross the roadway, they must be kept in repair, particularly at the ends, and there must be no doubt about their being clear. Particular attention is needed at driveways into abutting property or at road intersections to prevent obstructions to

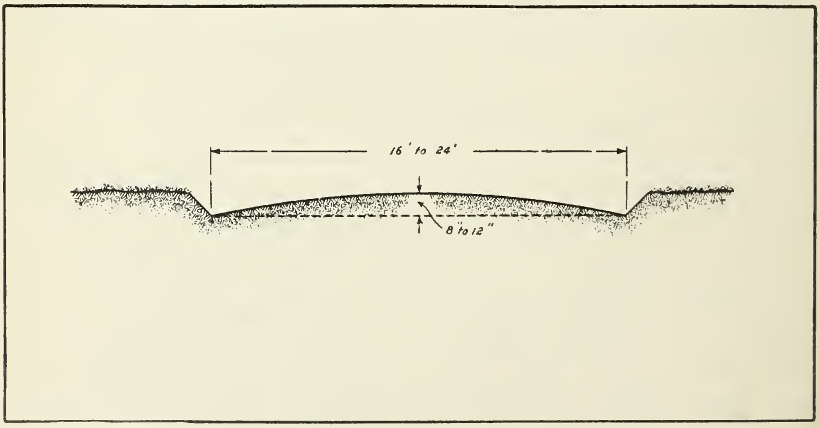

FIG. 5.—Cross section of another type of standard earth road.

drainage. Small pipes with shallow covering, leading under driveways, nearly always break and clog with refuse. In many places it will pay in the end to regrade the entrance and pave the gutter, leaving an open passage for water. Plate 1, figure 2, and plate 2, figure 1, show the results of imperfect driveway drainage. Even when suitable pipes are in place and well covered, if the driveway or intersecting road is poorly crowned, the surface flood water from adjacent land is carried directly on the road. This is prevented where paved gutters are used at entrances.

Underdrainage.—Underdrainage of a road has for its object the removal of underground water that comes nearer than 3 feet to the road surface. This subject belongs properly to road construction. In repairing earth roads, however, underdrainage of certain bad spots is the only effective method. Underdrains of various kinds are used. The sub-side-drain or French underdrain is one of the best. This drain is constructed under the gutter line on one or both sides of a road and is designed to cut off ground water before it gets to the roadway. A trench 3½ feet deep is dug about 15 inches wide at the top and with accurate alignment. The trench is "back filled"

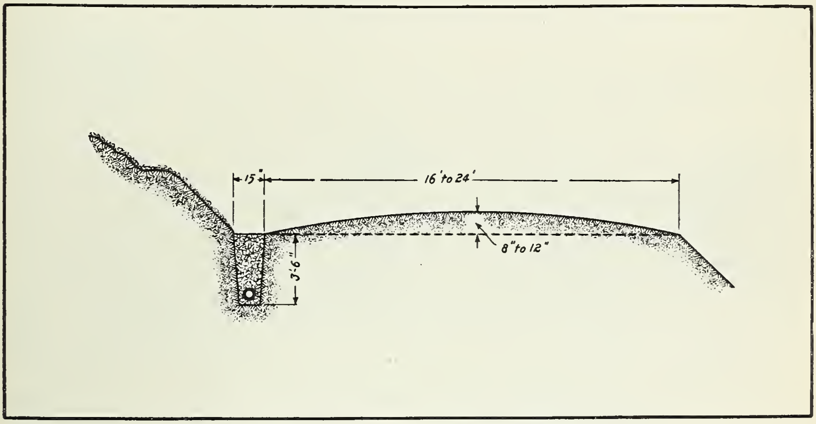

FIG. 6.—Cross section of a road showing side drain.

with broken stone or screened gravel and has a 6-inch pipe near the bottom, laid true to grade, with open joints. This side drain, if properly built, is very effective, particularly on hillside cuts or in wet subsoils. (Fig. 6.) It should be built with a view to service, whatever the future history of the road may be, and it needs a free outlet. Drainage of a road must keep water off a road, out of a road, and away from a road, and the road is not in repair until the drainage is perfected. Ordinary land tile is also used in a side drain instead of the vitrified pipe. This results in inferior construction, but it is sometimes justified. Low, seepy spots in a road can also be remedied by building a rough telford foundation or bottom of cobblestones set on edge with their longest axis across the road. This foundation must be put in by hand and the voids filled with sharp wedge-shaped stone splinters. The expense of such repair for obstinate wet spots is not very great if the stone is handy. The bottom stone should be covered with at *least 10 inches* of good live material. There should be one continuous patch underlaid with stone and not a series of "chuck" holes filled with stone.[1]

Scraping road grader.—That many country roads are never in repair is frequently due to defective drainage of the surface, because of

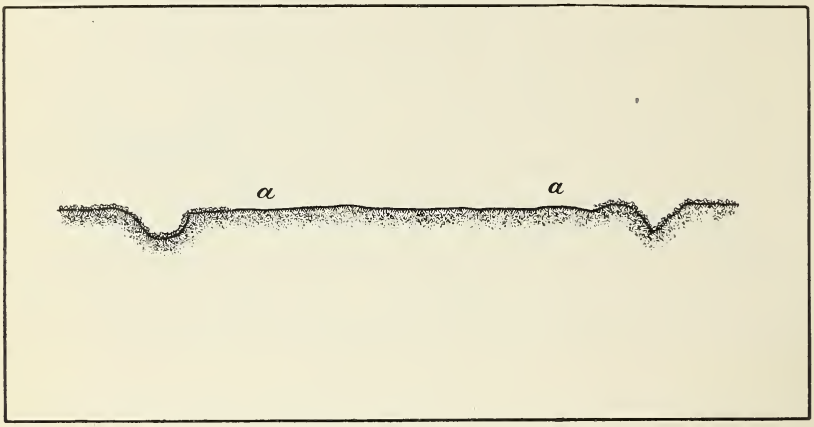

FIG. 7.—Cross section of a road showing defective drainage.

the development of continuous obstruction on the shoulder or quarter of the roadway at the points *a*, in figures 7 and 8. This obstruction may be due to a gradual lowering of the wheel tracks on the center of the traveled way; the presence of a footpath, which is avoided in

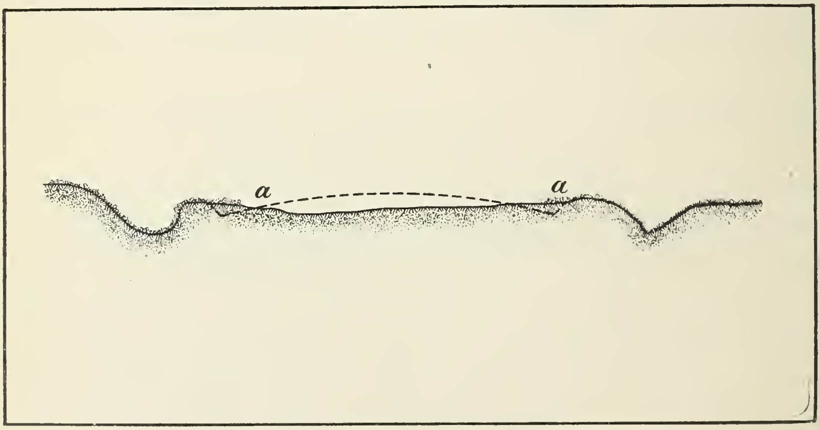

FIG. 8.—Cross section of another type of road showing defective drainage.

repair operations; or more frequently to the presence of sod; and often to all of these causes. If a road was originally crowned, the

[1] The V drain construction used in Massachusetts with a subgrade excavation 15 feet wide, from 6 to 8 inches deep at the edges, and from 12 to 18 inches in the center, "back filled" with stones varying in size from pebbles to 10 inches in diameter and with the larger stones at the bottom, is an excellent device. It must have frequent outlets. See United States Department of Agriculture Farmers' Bulletin 338, pp. 13–14.

fine-worn material is carried off to the sides by rain water. This material is rich in organic matter or manure, and when caught at the side of the traveled way causes rapid growth of weeds and sods. There is thus, in the lowering of the center by wear and rain, and the raising of the shoulders by sod growth and accumulation of waste, a twofold process tending to hold water on the traveled way. The bad section of road thus developed is shown in figures 7 and 8.

It is customary in many localities to remedy the above defects and repair earth roads from time to time with a road machine or road grader, types of which are shown in figures 9 and 10. These machines vary in size and require from two to eight horses to operate them. The blade of the road grader is designed to cut out and move a mod-

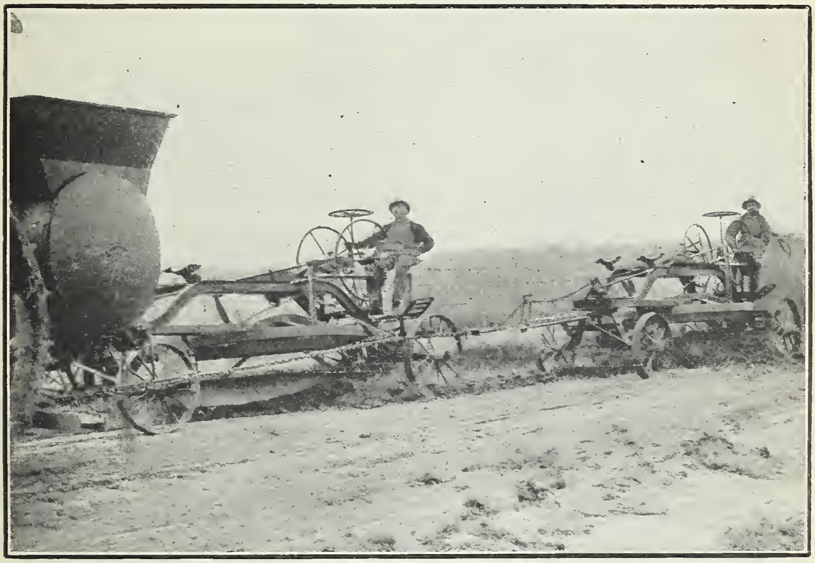

FIG. 9.—Type of power-propelled road grader.

erate quantity of earth in a direction at right angles to the road axis. The point of the blade should leave a clean, smooth cut. The earth is deposited past the heel of the blade and the blade may be raised at the heel to sink the point; the earth will then pass under the heel of the blade. This action tends to break clods and puddle the material. To work properly, the road machine must be well cared for and the blade kept sharpened and renewed when worn out. A road machine in bad order is a very wasteful tool, particularly when extra horses are added to compensate for worn-out blades. Where a steam roller or traction engine is available, it has proved very effective in operating graders and in handling material. It is well to begin operations with a road scraper just outside the wheel track and to work toward the gutters instead of beginning at the gutters and moving a constantly increasing mass of earth. In this way the blade always cuts new material, which moves freely toward the center.

When a road has developed a bad section (figs. 7 and 8) with high shoulders (that part of the road between the wheel tracks and the inside edge of the gutter), the road machine is used to remove the shoulders, renew the gutter, and crown the traveled way. To carry

FIG. 10.—Type of horse-drawn road grader.

out this work correctly the entire width between gutters must be scraped and no sod or other organic matter, or worn-out top dirt, or other dead material be put back permanently into the traveled way. There are two methods of procedure. Under the first method the road grader may scrape all the objectionable material with a light cut, even at the expense of some live subsoil, into long piles or windrows, which must be carted away to widen the slopes of fills or to supply the bottom layer for a new fill, or at the worst it may be piled up outside the gutters. The road section may then be re-formed with fresh material moved to the road center by the grader.

Under the second method no account is taken of the presence of sod or organic matter in operating the grader and the refuse is raked out or gathered with forks and removed in carts or sometimes thrown outside the gutter. A harrow may be used to reduce and separate sod when it is present in large masses.

Width of road.—Earth roads should not exceed 24 feet in width from gutter to gutter. Many roads are wider than this and allow a broad strip of sod and weeds to develop outside the actively traveled portion of the section. Such roads can not properly be maintained. All sod between gutter lines tends to encroach upon the traveled way and develop a secondary gutter, and to find its way into the middle of the road when the scraping grader is used. In certain sections where the rainfall is heavy and where there is wash of roads from surface water, sod is a necessary protection, but its development should be nevertheless controlled.

The road supervisor realizes often that he has not money enough to remove a broad strip of weeds and sod, and contents himself with removing a narrow strip next to the wheel tracks. A so-called "secondary gutter," which is not true to grade and which has no outlet, is thus developed. The road is consequently narrowed and the surface water can not escape into the original ditch. The section of the road resulting from this practice is shown in dotted lines in figure 8. The sod has been massed in the center to form a high crown. The entire operation is wasteful, and subsequent similar repairs become hopelessly confused and are at most a temporary benefit in dry weather. Nevertheless, when a road has an excessive width between gutters and must be repaired, there should be no hesitation in forming entirely new gutters. The road must in fact be given a new section and the section must be of uniform width [1] with even grades and outlets for the new gutters *at all low points* and at intermediate points on hills. Before using the road grader, stakes should be set and lines run to guide the workmen. Plows are sometimes needed to loosen the roadside. The sod and all other worn-out material containing no life and refuse must *under no circumstances be allowed to remain on the traveled way.* Such material, filled with organic matter, rotted leaves, and horse droppings promptly becomes mud, full of hoof marks and ruts which can not shed water. When once a load of refuse and worn-out fine soil is collected in a cart, the absurdity of placing it on the traveled way of a road becomes apparent. One or more teams and extra men to accompany the road scraper always are required to remove the sod and refuse.

[1] New York State standards: First class, 24 feet; second class, 20 feet; and third class, 16 feet. From New York State Highway Commission Bulletin No. 1, Road Red Book, 1910.

Sometimes when a road of proper alignment and width between gutters is out of shape, with high shoulders and refuse along the gutters, it is good practice to scrape off the worn-out material, rotten leaves, etc., by using the blade set first toward the gutter. After the road surface is clean and the refuse has been carted away it will be found that fewer trips have been needed and frequently that the road section is completely restored without disturbing the center. If, however, the center is still low, good live material may be scraped toward the center from the *shoulders.* Care must always be taken to *lower the shoulders* sufficiently to form a perfect crown instead of removing an excess of material from the gutter.

There are endless variations in the immediate causes of bad road conditions and defective repairs, but the discussion above outlines some of the worst and most prevalent.

Road repairing can be done, without a scraping road grader, by using a plow to break up the rough and rutted surface and then shaping the roadway with a split-log drag. The earth road may be first harrowed.

Surface repairs.—Seldom can an earth road be brought to a true section and given a firm traveled way without the addition of surface material at various places. This added material varies in amount from large patches to an application several hundred feet in length. Almost always there is on the line of a road or near the road some one best source of material, and that material should be used whenever considerable new earth is required. A road surface that is principally clay should be repaired with sand, and the two materials mixed with a harrow. If clay is available to spread upon a sandy road, the result is also very beneficial.[1] It is better to add new material in thin successive layers than to dump it in heaps. Hollows should be filled with the same material that is in the road. The old dust or mud should be first cleaned out, and great care must be taken to avoid the formation of a hard raised lump in the road, which will later develop two new hollows at the ends. Isolated patches of hardpan or gravel are of doubtful value when applied to a weaker surface soil, and "chuck" holes must never be filled with cobblestones. It is better practice to break up the surface and, after smoothing it with the grader, to add a continuous layer of the best new material of at least 8 feet in width along the actual traveled way, taking care to taper it to a feather edge at the ends and sides.

Where a road is sand from one to several feet thick it is in its best condition when damp, and the crown may be made less. In this case no side ditches are required. Clean straw spread over a loose sand road is effective for a short time in preventing wheels from cutting,

[1] See U. S. Department of Agriculture Farmers' Bulletin 311, "Sand-Clay and Burnt-Clay Roads."

but this is a makeshift. A road in clay soil should be finished with deeper ditches and more crown than on the typical earth section.

SAND-OIL SURFACE.

A successful treatment of pure sand roads has been adopted by the Massachusetts State Highway Commission. Where the subsoil of the road is entirely beach sand or equivalent pure sharp sand, what is known as sand-oil roads have been built. After the road is graded and rolled the heated asphaltic oil is applied at the rate of about three-fourths gallon to the square yard. The oil is then covered with all the sand that it will absorb and rolled with a light roller. Then two other applications, using less oil, follow. The road is then again covered with sand and rolled and a final coat of about one-half gallon of asphaltic oil to the square yard is applied and sanded. The road is then thoroughly watered and rolled. It is necessary to have the subgrade hard and well shaped and to spread the oil uniformly. It is expected that this form of surface may require reshaping and some treatment the second year, and sometimes the third year. The process is essentially a building-up method to secure a uniform smooth roadway. The average cost of such treatment of sand roads is about 44 cents a square yard.

GRADE AND ALIGNMENT.

The matters of grade and alignment of a road belong with its construction, but, inasmuch as no road can be considered in good repair until its grade and alignment are reasonably corrected, it is necessary to class the required operation with periodic repairs. In fact, it will always be necessary to *improve* earth roads simultaneously with their repair. All that many earth roads can hope for is periodic repair. Reduction of some heavy grades and removal of unnecessary turns should be included in all repair operations, although they are permanent improvements.

Even with small appropriations for repair and maintenance, some permanent repair work should be done. Expenditure for grade reductions must be decided in advance. Beginning with the worst grade, unless it is ledge, a layer of material should be cut out for use on low spots or to raise the grade elsewhere. Wheel scrapers and slips are economical for such work when the haul is not excessive. Before any extensive grading is done it is always justifiable to employ a surveyor to establish a grade and to set grade stakes from time to time, so that a good profile may be gradually developed from year to year. It must always be remembered that good grades and alignment are necessary for good drainage and that good drainage is the very life of the road.

The ultimate object of earth road repair and improvement should include, on roads of the first class, the establishment of such lines, grades, drainage, and section that these roads may in the future be given a hard surface and may advance into the class of modern improved roads for the least investment of public funds. In a similar way roads of lower types should be so treated that their condition improves and that their advance into the next higher type is assured with the least expense.

There are many special conditions of soil, climate, and topography which govern the details of earth-road repair.[1]

These matters are further discussed under the subject of "Road management," (pp. 53–68).

MAINTENANCE OF EARTH ROADS.

To preserve a properly built or repaired earth road, it has been repeatedly demonstrated that the best method is some system of continuous maintenance. Continuous maintenance prevents the necessity of extensive repairs and keeps the road always in good condition. The operations involved in maintenance are in one sense small repairs. The economy in small repairs over extensive periodic repairs is largely due to the fact that defects in a road develop at an *increasing* rate if allowed to continue, and the cost of restoring the road to the normal condition is consequently made greater than the actual sum of the costs of repeated minute repairs. The advantage to the traveling public in continuous maintenance is self-evident.

THE ROAD DRAG.

The split-log drag, or some of its modifications,[2] has proved beyond doubt the best tool for earth-road maintenance. It is sometimes called the road hone. This drag may be made with either two split halves of logs, from 6 to 8 feet long and 6 to 8 inches thick, shod with iron, or with planks from 3 to 4 inches thick shod with iron, or sometimes by splitting a railroad tie with a saw. It is drawn by two horses and is designed to run at an angle to the axis of the road. The object of the drag is to move a small quantity of earth and also to puddle the surface. The two half logs are set parallel, about 3 feet apart, with the smooth sides facing forward, as shown in figure 11. They may be connected with any desired system of braces, about 6 inches from the ground, but the drag should be rigid, and that is best secured by having two diagonal braces. The iron shoe has

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[1] Cf. U. S. Office of Public Roads, Circular No. 91, "Sand-Clay and Earth Roads in the Middle West"; Circular No. 95, "Special Road Problems in the Southern States"; and U. S. Department of Agriculture Farmers' Bulletin No. 311, "Sand-Clay and Burnt-Clay Roads."

[2] Cf. U. S. Department of Agriculture Farmers' Bulletin 321, "The Use of the Split-log Drag on Earth Roads."

been successfully made from old wagon tires. In stony soils the iron shoe should extend the entire length of the blade. The position

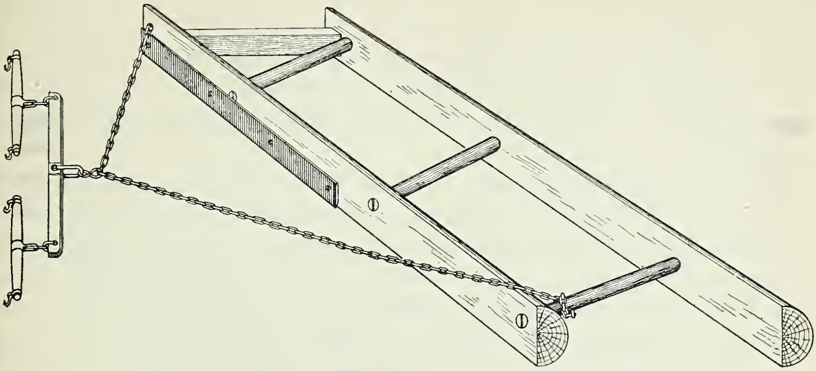

FIG. 11.—Perspective view of split-log drag.

of the hitch ring governs the angle at which the drag cuts the road. The angle should be about 45°. There should be a plank for the

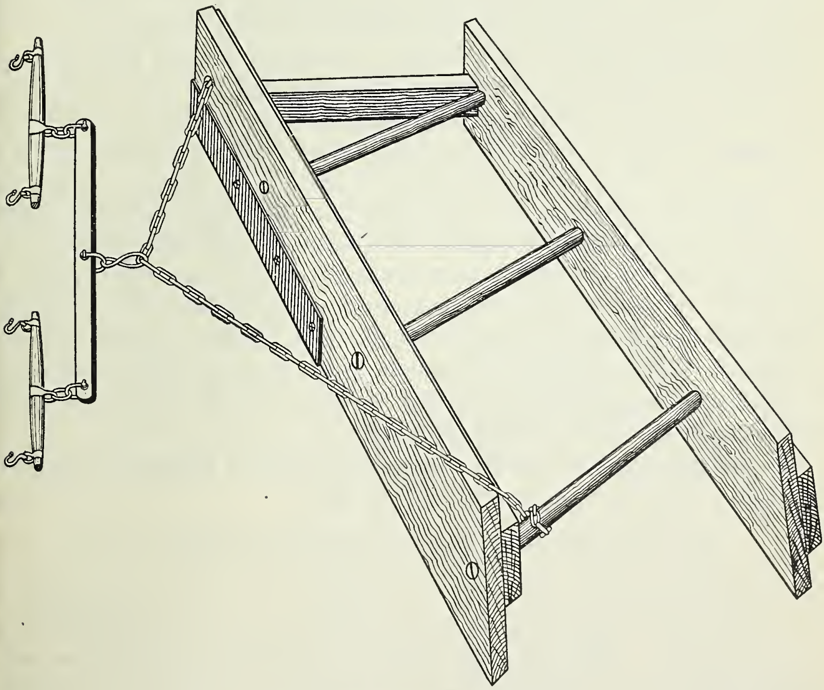

FIG. 12.—Perspective view of plank drag.

driver, who should ride the drag. Some operators attach handles similar to plow handles, weight the drag with stone, and walk behind it to direct the movement with the handles. The construction of the plank drag is sufficiently clear from figure 12. Another form of road drag is made from two 8 or 9 foot pieces of railroad rail, and this is very effective.[1]

The necessary features of the road drag are lightness, rigidity, and durable edges. The cost of a split-log drag should not exceed $5 when built by a carpenter. An oak plank drag is slightly more expensive.

The road drag is designed to reduce ruts by paring action and to smooth and harden the surface of a traveled way, and it does both. The action of the drag involves the movement of a *small* quantity of earth combined with a puddling action. It is not intended to grade a road as a road grader does. When the drag cuts too deeply, the hitch may be shortened. When it slides excessively with a long hitch, weight may be added temporarily to insure some cutting. The best time to use the drag is after a rain, as the surface of a road is then soft enough to be cut easily and is in the best condition to puddle. By its capacity to move small amounts of earth toward the center, the road drag maintains the correct crown, which always tends to flatten. By its capacity to puddle the surface, the drag builds up successive thin layers of material, which gradually become waterproof and harden while drying. Dragging should begin at the outside of the road and progress toward the center. The road drag is not a cure-all for bad roads, although almost any road is helped by dragging. To secure the best results the road should be in good repair as to section and drainage, and the drag should be used often, especially in the first season. An old road, full of cobbles used to fill "chuck" holes, can not respond to dragging. The drag should be used always when the road is wet but not so sticky that mud clings to the blades. This is often the case in the black soils of the Middle West, and a smoothing drag or slicker is used successfully in such conditions.[2] Dragging a dry road is of no benefit. The road drag consequently is peculiarly adapted to a system of continuous road maintenance, and the annual cost is low.

The following is the record of dragging a road in Arkansas, $1\frac{3}{4}$ miles in length, with an average width of 30 feet:

TABLE XX.—*Record of use of road drag in Arkansas.*

	1907										1908	
	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Number of times	$3\frac{1}{2}$	6	3	1	1	1	0	0	3	4	5	11

[1] Various forms of road drags or road hones are shown in New York State Highway Commission Bulletin No. 1, Road Red Book, pp. 77 and 79.

[2] Cf. Illinois Highway Commission Report for 1908–9.

The cost of this work for a year was at the rate of $11 per mile, or 50 cents a dragging. The low cost was secured because the only charge was for the driver's time. Before this road was dragged it was possible to haul at most one bale of cotton with two mules, and sometimes the road was impassible. After the road had been dragged for some months two mules could haul from 10 to 12 bales of cotton at any time.

Ordinary dragging for the first year can be done at the rate of about 4 miles of road per 10-hour day on an average and will cost, therefore, from 75 cents to $1.25 per mile, with a dragging of three round trips. The average cost of a mile of dragging on 8 miles of experimental road maintained by this office in Alexandria County, Va., during 1911 and 1912 was a little less than $1.25 for three round trips. The cost was based on 24 complete draggings during the first year. After the first year or two, roads can be kept in excellent shape at a cost of from $6 to $12 per mile. The hardest part of road dragging is to make a beginning. The first dragging may not produce much apparent benefit, and the operation requires patience and persistence. The road should be dragged the entire length of the section, which should be such as can be finished in one day. Where the travel after dragging tends to form two tracks with a center ridge of loose earth, the drag should be run directly in the center, or a slicker or clod smasher may be used to reduce the ridge. One immediate result which is beneficial will be the distribution of travel, which is prone to follow ruts. Repeated draggings will eventually produce a harder surface, which sheds water well, and a good crown, which should be kept about 1 inch to the foot except on heavy grades, where the crown may be increased to shed water more quickly. It must not, however, be expected that the road drag will maintain in good condition a wet clay road or an earth road on which the travel really demands hard, modern road pavement. The amount of dragging necessary tends to diminish slightly as the work continues, first, because it is not necessary to drag the full width each succeeding time, and, second, because the effect of dragging lasts for increasing intervals as the road takes on a firm surface and good section. Good results of dragging are shown in Plate II, figure 2, and Plate III, figure 1.

MANAGEMENT OF DRAGGING AND THE PATROL SYSTEM.

The essential factor in earth-road maintenance by dragging is to have a definite mileage of road in charge of a responsible man who owns a team of horses and lives on or near the road. Dragging can seldom be arranged to occupy the whole time of a team, and some form of unit price is, therefore, required. As a rule, when a general system of road dragging is established in a community, a healthy spirit of rivalry develops among the men in charge of separate sections and good results follow. Frequently in rural sections the dragging is done when the team would otherwise be idle.

The patrol system has prevailed in the past largely on macadam roads. In France up to within a few years it was universal, and the French roads were the best maintained roads in the world. The system allots a definite section of road to the care of a man who puts all his time on the work, and he is expected to supply hand tools and a horse and cart. An objection has been raised to the patrol system on earth roads because of the expense. The wages of the patrolman employed continuously eight months of the year may result in apparently excessive mileage costs. The excellent results of continuous patrol work are, however, so certain that a patrol system combining dragging should be tried before dismissing the plan. There is more or less continuous hand work involved in all earth-road maintenance. Such work includes clearing side ditches of all obstructions, reducing water-breaks, repairing wash damage during and immediately after storms, keeping culverts and driveway drains free at all points, placing new material on the traveled way, removing loose stones, and caring for the right of way. Such work prevents expensive repairs. The care of the right of way includes clearing brush and cutting dead and other objectionable trees, removing weeds, trimming gutter lines, etc. Leaves on a road are a constant menace to drainage and produce a poor surface condition when wet and ground into the soil. It is perfectly clear that after a time work on the right of way and drainage may be reduced to a small fraction of the original amount, and still there is a residue of necessary constant hard work. It always pays to have a man on earth roads part of the time, and strict maintenance can not otherwise be realized. A good system of maintenance should include a traffic census taken systematically and thoroughly, especially on roads which indicate the need of some form of hardened surface.

An experiment in road-patrol work on earth roads is in progress under the direction of the Office of Public Roads at the present writing. It has already been shown that expense due to damage by flood water in the ditches and on the slopes can be prevented by the presence of the patrolman, and that there is no difficulty in maintaining a good smooth road when it is once put in proper repair.

GRAVEL ROADS.

REPAIR.

The repair and maintenance of gravel roads is very similar to that of earth roads. Before a gravel road can be effectively maintained it should be put in thorough repair. The repair should restore, in the first place, the drainage structures of the road to proper condition.

FIG. 1.—GOOD ROAD CROWN MAINTAINED BY DRAGGING, ALEXANDRIA COUNTY, VA.

FIG. 2.—CLAY-GRAVEL ROAD IN VIRGINIA MAINTAINED BY A ROAD DRAG.

The graveled way itself is repaired by first clearing away all refuse and vegetable matter or other perishable material which may have worked on the surface from the sides or otherwise. The road should then be carefully reshaped by a scraping grader and by hand work with rakes. Sometimes a harrow is useful. Unless the road is directly underlaid with pure sand or clay, there need be no hesitation in breaking up the old hard surface, for a new layer of gravel will not otherwise bind well with the old layer. If there is an excess of large pebbles or stones on the surface, these should be removed, or they may be used, if of sufficient amount, as a new bottom course on some considerable section of the work. New gravel may then be applied for a wearing coat. Before beginning this operation earth shoulders should be thrown up to hold the new material and to prevent waste. Gravel in the wearing course should not contain pebbles greater than 1 inch in diameter and should be uniform.

The best gravel for repair, as for construction, is that gravel formed by the breaking down of trap rock. Such gravel is found in glaciated portions of this country in banks, and possesses desirable road qualities comparable with the original trap rock. All gravel used for resurfacing work should contain about 60 per cent of pebbles, varying in size, and an adequate amount of fine binding material or sand.[1] Where gravel contains an excess of sand, it does not bind and form a hard, smooth surface. A moderate amount of clay is not harmful, but where considerable clay is present, the gravel becomes softened in wet weather and the road may go to pieces. It may sometimes be necessary to screen gravel into sizes for repair work as in gravel construction. The "fines" should not be piled on top of the road in a thick blanket, however, but only enough should be used to fill the voids. Excess "fines" not containing clay may be used as a sublayer in low spots. If the repair work is done in a dry season, the repair course should be thoroughly sprinkled. Rolling with a 10-ton roller, while not absolutely necessary, is a great advantage to repair operations on gravel roads. If the repair is made in the spring when the frost is out of the ground, the road will have the benefit of the entire season's travel to consolidate it and prepare it to withstand the severe conditions of winter. Where automobile traffic is excessively heavy during the summer, it will be of advantage to do the gravel work in the fall and allow it time to consolidate before being subjected to the action of motor wheels. The amount of gravel necessary for repairing gravel roads is, of course, governed by the general conditions of the road. If a road has been allowed to continue uncared for, it will require from 4 to 6 inches of consolidated gravel as

[1] Everything passing a $\frac{1}{4}$-inch mesh screen is rated as sand. Good gravel pebbles for road work should pass a mesh or ring of $1\frac{1}{2}$ inches and 80 per cent should pass a 1-inch ring or mesh.

a repair surface. The cost and quality of gravel vary greatly in various parts of this country.

There are certain principles which govern the repair of gravel roads as well as their construction, and the following should be mentioned as important: Where gravel must be imported by railroad, the freight and hauling costs make it nearly as expensive as broken stone, and it is doubtful policy to use gravel under such conditions, unless broken stone is out of the question. As the cost of gravel delivered on a road job depends largely upon the length of haul, it should not be brought from a distance until it is absolutely certain that no deposit can be found in the neighborhood of the work. It frequently happens that a careful examination discloses the presence of good gravel close to the work, even in many instances where it has been customary to haul gravel from a certain well-known bank. Before regraveling any road a painstaking examination should be made of all possible sources of material.

Quite frequently it is desired to repair an earth road by supplying a gravel surface. On such work it must be understood at the outset that patching a soft earth road with gravel in small spots is of no value. Gravel should be applied in continuous uniform layers, otherwise "chuck" holes will rapidly form at the edges of all patches. It has been unfortunately the misguided practice of many road supervisors to dump loads of cobbles and gravel where mudholes are present in an earth road, and some of the worst earth-road conditions at present are due to the repeated dumping for years of such material.

A gravel surface can not "stand up" under traffic as a macadam road does, and every precaution should be taken to prevent the tracking of vehicles in one rut. It is desirable to have a gravel road crowned at least three-fourths inch to the foot, and, as it will always tend to flatten somewhat, it is well to have the crown a little excessive on a new road surface. It must be remembered, however, that a sharp crown on a narrow road tends to make team travel in one track exactly in the road center. It is clear, therefore, that gravel roads should be as wide as needed to carry the traffic.

The details of hauling and spreading gravel on roads require careful consideration. It is always possible to relate the number of men shoveling at the pit to the number of teams hauling in such a way that no time is lost either in loading or in depositing gravel on the roadway. With a little study, teams may be properly spaced and the men disposed so that much money is saved when the job is finished. In repair operations with gravel, it is desirable to spread the gravel carefully by hand, but a careful operator on a road-scraping machine can do an excellent job and much cheaper. The road surface should be well established by lines and shoulders and, if possible, rolled before any new material is spread. If the gravel is merely dumped upon the surface and roughly spread with shovels, a good job will not result. It is usually necessary to have one or more men with rakes who can constantly remove larger stones and keep them ahead of the dump in the bottom of the layer. If large stones form a considerable percentage of the gravel, men should be placed with rakes at the pit or on the road to remove them. Frequently there is sufficient gravel on the road and it requires only reshaping with the grader to put the road in good condition for maintenance.

The use of bituminous binder on gravel surfaces has produced good results. The essential requirements are the use of well-graded gravel with no large stones or pebbles in the upper layer and a thorough mixing of the binder with the gravel. Large stones on the surface tend to start ravel. It appears that the lighter asphaltic oils mix more readily with gravel and may be incorporated after applying by using a spring-tooth harrow. Usually a new application of asphaltic oil will be required after one or two seasons where there is heavy frost. Where light asphaltic oil is applied to a gravel-road surface, a brush harrow has been used to mix the oil and gravel with good effect. (See pp. 43 et seq.)

MAINTENANCE.

A gravel-road surface may be effectively maintained by the use of hand rakes, a scraping grader, and sometimes by the split-log drag. The ruts and horse track which develop may be filled by raking for a time, but later new material must be added. When holes are to be filled, they should first be cleaned of dust or mud and the edges loosened with a pick. Sufficient gravel of the proper size for such work should be placed along the road at intervals. The piles should be large enough not to be scattered and wasted, and a careful record of the quantity should be kept. It is inevitable that larger stones will gradually work to the surface, and they should be removed by rakes or picked off the road by hand.

A split-log drag or a plank drag can be used advantageously in gravel-road maintenance when large stones have been removed. Sometimes a scraping grader is useful in reshaping gravel roads. The main benefit from the road drag is due to the smoothing of incipient ruts and the constant preservation of the crown. If serious ruts begin to form at the edges of the road, they may be refilled by hand raking to good advantage. The material should be drawn always to the center as the gravel tends to work outward. In using a road drag upon gravel surfaces, it is desirable to have both blades of the drag shod the entire length with strips of iron with the dimensions 2 inches by three-eighths inch in section. It is well wherever possible to roll gravel roads once a year. Plate III, figure 2, shows a clay-gravel road in Virginia maintained by a road drag.

Table XXI shows the actual expenditures on 175 miles of gravel roads in Bennington County, Vt., for repair and maintenance during the season of 1912. The average cost must be regarded as somewhat low as a general figure, first, because of the unusual supply of native gravel, and, second, because the roads are protected from wear by snow for several months each year.

TABLE XXI.—*Repair and maintenance of gravel roads in Bennington County, Vt., 1912.*

Town.	Number of miles.	Total cost.	Cost per mile.
Arlington	13	$267.00	$20.53
Glastenbury	3	32.92	10.97
Landgrove	7	158.41	22.63
Manchester	17	361.48	21.26
Sandgate	15	301.87	20.12
Searsburg	6	90.45	15.07
Shaftsbury	13	269.30	20.71
Stamford	10	205.64	20.56
Winhall	9	291.00	32.33
Woodford	12	347.28	28.94
Pownal	17	315.75	18.57
Peru	14	282.92	20.21
Rupert	15	300.45	20.03
Readsboro	16	227.82	14.24
Sunderland	8	171.74	21.40
Totals	175	3,624.03	[1] 20.71

[1] Average cost per mile.

REPAIR AND MAINTENANCE OF SAND-CLAY ROADS.

All the general features of maintenance, such as clearing waterways and dressing shoulders, apply as well to sand-clay roads as to metaled roads. In all cases the cross section should be carefully maintained to insure good surface drainage, and all ruts, hoof marks, and depressions likely to hold water should be smoothed away, so that there will be no standing water on the road. The special feature of sand-clay maintenance is the repeated smearing of the surface to close it against the penetration of moisture as far as practicable. The best method of effecting this is to use a simple drag, such as the split-log drag, as frequently as the surface seems to need it. In the first wet season following construction a sand-clay road will probably require dragging after every shower of much length. Later the need of dragging will probably be less, until finally about 10 thorough treatments each year will suffice to keep the surface in satisfactory condition.

The dragging should always be done after a rain when the surface is plastic. There are two periods following rain when the soil is in suitable condition for dragging. The first period is almost immediately following the rain when the road is very wet and soft. Then follows a period when the soil is too sticky for dragging, and this is followed by a third state when there is a process in the soil analogous to setting, and at this time the dragging is of greatest benefit.

The road surface is still plastic, but the mud does not adhere as badly to the drag. The surface can be smeared or plastered down, dressed free of all ruts, hoof marks, or minor depressions, and by careful use of the drag such small quantities of material as may be required can be shifted back and forth across the road.

Dragging should be begun along the outside edge of the traveled way, and the first return trip should be along the opposite edge. It should advance toward the center, and the last trip should be made directly in the center with the drag linked up straight so as to spread the accumulated material evenly.

A cutting edge on the drag should be avoided and, if a metal strip is used to reduce wear, it should be set flush with the edge and not projecting.

If at any time the road becomes badly worn or out of shape, the entire section should be plowed, disk harrowed, reshaped with a drag or grading machine, and rolled. It is not uncommon when sand-clay roads are new to find that there is an excess of clay. In this case there may not have been sufficient sand used in construction or it may have been lost by wash into the gutters. There should be a sufficient supply provided on the roadside to restore the proper mixture, particularly for the first season or two after construction.

In case the road hardens in a rough condition, owing to careless dragging or to neglect, a grading machine will re-dress it satisfactorily. Frequently by reversing the blade of the grader the effect of an excellent heavy drag is produced that will iron out hardened ruts and hoof marks.

As has been said (p. 47), about 4 miles of road can be thoroughly dragged in one day for from five to six trips over the section. Ten treatments a year would therefore cost about $40 for 4 miles or $10 per mile per year for dragging.

ROAD MANAGEMENT.

The repair and maintenance of public highways has suffered greatly from poor administrative systems. Such work is necessarily of a more routine character than the work of new construction, and the failure to recognize its importance has in the past led road officials to subordinate it to the execution of new work. It would seem that at just the point in road operations where stimulus of effective organization was most needed it has been absent. The only successful attempts at systematic repair and maintenance that are on record are those attempts which have been managed with skilled and strong central control. Almost without exception, those States which have undertaken State aid in any form for road building have, in the annual reports, reiterated the necessity of removing the responsibility of repair and maintenance of such roads from local authorities. In a number of States this change has been made, and the results have been an immediate improvement.

Viewing public roads as a whole, the defects of subdivided administrative units are conspicuous. The number of men who have more or less authority and personal direction over road matters in some sections of the country is extraordinary. There are at least 150,000 such road officials in this country. The term of office of these men is but a year or two, and rotation in the office tends to be the rule.

A fundamental difficulty with the organization of road systems which must handle repair and maintenance appears to be the failure to recognize that road work is a trade which requires training. Training for road work must necessarily be obtained at the expense of the community. As a rule, road officials are not in office long enough to mature their experience, and there is a constant economic waste of road funds.

Repair and maintenance operations upon all public roads necessarily extend over a period of years. In order to secure effective execution of such operations, a comprehensive plan for several years is necessary. The work for each season must be carefully laid out in advance as far as possible. Where maintenance work has been seriously undertaken under such a system it has responded with gratifying results. Whatever the civil subdivision may be which constitutes the administrative road unit, a good road map showing all the various classes of roads is desirable.[1]

It has been found that the best results follow in an administrative district where the mileage of roads is sufficient to warrant the continuous employment of a man who is either a highway engineer or a competent road builder, whose interest is primarily in road work, and who has charge of road matters in his district. Where such a man is employed from year to year he can select competent men for road work, and he is able to plan with confidence systematic improvements which must wait for successive annual appropriations. Good business organization in road work demands an adequate bookkeeping system from which unit prices for various classes of work can be easily derived. Too frequently road accounting presents an accurate list of men to whom money has been paid for material or labor, but from which no estimate of the cost of future repair and maintenance work can be established.

It will be more and more necessary in the future to study the service of various roads by accurate traffic censuses. From the investigations that have already been made, it appears that for any

[1] The State of New York has undertaken the preparation of a comprehensive atlas of all its roads; roads are drawn uniformly one-fourth inch in width at a scale of 1 mile to 3 inches, which allows all culverts and bridges to be shown. The Ohio State Highway Department has issued Bulletin No. 11, giving maps of all roads in the State by counties. In this document also the scale is 1 mile to 3 inches.

civil subdivision a relatively small percentage of all the roads carry nearly all the travel. In France a traffic unit called the "collar" is used. The "collar" is a single horse harnessed to a vehicle, and all other traffic is reduced to "collars," including automobile traffic. The "collar" has not been adopted in the United States as a traffic unit. It is unfortunate, moreover, that no agreement exists among road men at present as to the detailed method of measuring traffic. Traffic censuses were taken in Illinois in 1906–7, in New York in 1909, and in Massachusetts in 1909 and 1912. These censuses counted the travel, but no common unit is yet available for reducing such traffic data; moreover, the useful tonnage is a most important item from an economic standpoint, and it is seldom counted.[1] It is well established that an improved road draws to itself increased traffic. To determine the future use of roads, it will be necessary not only to know the travel passing over the road before improvement, but also to know the increase of travel which is likely to be diverted to the road when it becomes improved. It is undeniable, moreover, that travel upon roads in general is rapidly increasing numerically in tonnage and in mileage of travel radius. Preliminary study is clearly necessary, therefore, to enable road men properly to relate the first construction costs to probable maintenance charges. There should be an ample "factor of safety" in road design to allow for increased service.

Under a competent and continuous administration there are many details which can be worked out for road betterment which are otherwise neglected. It is necessary for economy to have the location of deposits of all road material within a road district placed on the road map and the quality of each deposit carefully recorded. The care of all road machinery should be in competent hands, and it should be housed and ready for use when the season commences. A gradual improvement in the grades of more important roads can be undertaken with an established profile toward which some work is directed each year. It is quite probable that the prevailing lack of permanent culverts and bridges on highways is partly due to the unwillingness of short-term road officials to spend a considerable amount of money in one place. Under a continuous administration some permanent culvert or bridge work may be undertaken from time to time along a plan which contemplates the final improvement of all such structures. Concrete culverts and bridges require almost no maintenance charges, whereas wooden bridge floors and culvert bridge floors must be renewed every few years.

It is probable that the continuous employment of road patrols will be too expensive for a large part of our road mileage for some time

[1] The Massachusetts census of 1909 and the census of 1912 determined the estimated gross daily tonnage as 344.8 and 647.3 at 247 and 156 stations in the two respective years.

to come. It is equally true, however, that on many miles of road the presence of a road patrol at a cost of from $60 to $75 per month will be economy.[1] It has been repeatedly observed that the work of such roadmen in preventing water breaks and wash from rain storms and thaws at the right time has in itself justified their salaries. Whatever system of road labor is adopted, the work should be organized early in the year and experienced men developed and retained as far as possible. The foreman of a repair gang on road work should have sufficient knowledge and experience to justify spending his entire time in supervising and planning the work without attempting to labor with his men. The element of thoroughness in details, such as complete cleaning of mud holes, *sufficient* material, *swift* repair of water-breaks, etc., can not be over emphasized. There is always enough necessary planning and supervision to keep a good road foreman occupied.

The supply of road material for repair and maintenance operations should be at frequent intervals along all roads—that is to say, for example, there should be sufficient broken stone of both sizes and screenings at hand on all macadam roads and the quantity should be known. With the increased use of bituminous material, it is necessary also to supply at convenient intervals stores of such material, and men working on the roads must be furnished with necessary small tools, including tar kettles, heating apparatus, pouring pots, and stiff push brooms.

On the Continent of Europe and in England, where road repair and maintenance have been conspicuously successful, it has been the practice to issue printed instructions covering the smallest detail to all men engaged in the work. It is also the plan to require reports of work done and quantities of material used at frequent intervals, and sometimes daily. Roads are frequently inspected and accurate estimates of all quantities of work are made from year to year.

Larger jobs of repair are usually most advantageously handled by contract. Contract work must, however, be done under competent inspection and with proper plans, profile, and written specifications. Where road work is in continuous charge of one competent man, it is possible for him to gain information from time to time which fits him to draw up proper specifications, avoid the repetition of mistakes, and benefit by the experience of other highway engineers. With a rotation of road officials there is little incentive for a man to familiarize himself with the best practice. He is not interested primarily in road matters and can not be expected to educate himself by reading road journals or attending road gatherings.

[1] A continuous maintenance gang of foreman and 8 or 10 men, with suitable equipment, is a practica and economical maintenance force for county-road systems, aggregating 100 miles or more, where a patrol system can not be economically established.

Repair and maintenance have not been given sufficient consideration in planning road finances. It is becoming yearly more common for local authorities to issue bonds for road construction. During the year 1912 nearly $29,000,000 in bonds were issued by counties and road districts in various parts of this country for road construction. It is not uncommon to find such bond issues planned with no provision whatever for a repair and maintenance fund. No road can last 30 years without repairs, yet 30-year bonds are repeatedly issued for road improvement. Many such bonds are commonly issued and the proceeds are expended without adequate supervision and under weak administrative systems. Every bond issue should be accompanied by a direct tax providing sufficient revenue for the upkeep of the roads with a good margin of safety, and the term of the bond should in most cases be shortened. Without doubt a serial bond is to be preferred to the form of retirement by a sinking fund. Serial bonds may be arranged so that the annual tax for interest and retirement is constant. With a serial bond there is a large percentage of the road actually paid for before it is worn out, even with long-term issues.

There is apparent contradiction in the cost figures for repair and maintenance exhibited by expenditures on roads of a given class as a whole and the figures obtained by analysis of the cost of necessary operations on a given type of road. On a 15-foot bituminous-macadam road an annual charge of $700 a mile is nearly 8 cents per square yard. Although the cost of repair and maintenance in a number of States has recently averaged above $700 per mile, the annual cost of necessary operations for repair and maintenance by any given method is, on an average, considerably less than 8 cents per square yard. The average cost of repair and maintenance for eight years in five States is shown in Table XXII.

TABLE XXII.—*Repair and maintenance expenditures in Connecticut, Massachusetts, New Jersey, New York, and Rhode Island.*

Year.	Miles.	Appropriations and expenditures.[1]	Rate per mile.	Year.	Miles.	Appropriations and expenditures.[1]	Rate per mile.
1905	[2] 668	[2] $60,777	$100	1910	5,572	$4,336,201	$778
1906	[3] 2,125	[3] 624,696	294	1911	6,183	4,491,718	[4] 726
1907	3,303	1,024,096	310	1912	7,300	5,945,084	814
1908	3,906	1,441,502	369	Average for eight years			608
1909	5,161	2,880,272	558				

[1] Includes town and county expenditures and available automobile revenue.
[2] Connecticut, New Jersey, and New York not included.
[3] Connecticut not included.
[4] New York appropriation late; repair and maintenance work not completed.

The apparent contradiction is partly due to the excessive accumulation of resurfacing charges. Resurfacing charges have recently risen because of the particular phase of average-life period reached by a large mileage of State-aid roads and because of the emergency created by the new traffic, and especially because of the combination of the two causes. In so far as surface treatment is absolute maintenance, this present prevalent method of maintenance includes the former annual resurfacing charges which ordinary macadam roads required, but which for a number of years did not appear in the repair and maintenance figures. The present years are, therefore, bearing not only accumulated past resurfacing charges, but are now carrying an increment of annual cost directed toward the increased life of the new road surface.[1] It is possible, however, that considerable resurfacing of bituminous-bound macadam roads will ultimately be necessary, and in this case there will be a rise in repair costs when the life period is reached. Maintenance of roads subject to automobile traffic tends more and more to become absolute maintenance. Not only does automobile traffic become increasingly destructive to a road which is once allowed to ravel, but the reaction of road surfaces upon automobile tires is now a matter of much importance.

Increased knowledge is needed of the actual relations between first cost and interest and of the life, service, and maintenance cost of the road. In future investigations for determining the type of road to be built it will be necessary to provide for large increases in traffic and carefully to balance the advantages of long-lived road surfaces, such as concrete and brick, with low maintenance costs, against the lower-cost road surface, with little or no factor of safety and immediate and high maintenance costs.

The discussion of the repair and maintenance of concrete roads is omitted in this bulletin because no sufficiently accurate or representative data yet exist either as to method or cost. The repair and maintenance cost of brick roads has repeatedly proved to be very low, and, in fact, nearly negligible, when the best modern construction is employed. There are not yet sufficient data from State authorities to warrant definite conclusions as to actual annual repair and maintenance figures.

MASSACHUSETTS.

The experience in the State of Massachusetts in the matter of repair and maintenance of State-aid roads is worthy of attention.

In the early years of construction in Massachusetts maintenance was carried out by the employment of local labor, under the direction of the division engineer of the State highway commission, and by

[1] Assuming the cost of bituminous resurfacing at 72 cents per square yard; the annual maintenance, including necessary surface treatment, 4 cents; and the total annual charge for ordinary macadam resurfacing and maintenance, 5.9 cents; then if it is desired to find how long a road reconstructed with bituminous surface must wear, without resurfacing but with regular surface treatment, in order that the total annual cost shall be the same as for ordinary macadam, there results from the above figures (n= number of years)—

$$\frac{72+4n}{n}=5.9,$$

whence n=37.9 years, nearly.

contract on certain lengths of road where the consecutive mileage justified such contracts. The work consisted in repairing damage due to wash and freshets on the slopes and in the proper care of drainage features, such as cleaning gutters, culverts, and catch basins. The maintenance of the roadway itself included the removal of loose stones, the repair of wear in the center due to horses' feet, sanding the roads, and supplying binder in dry weather to prevent raveling. When this work was done with local labor the maintenance was not considered continuous, but on the contract sections the contractor was required to do whatever work was necessary at all times. The commission supplied stone along the road at proper intervals. When the roads were new a considerable part of the maintenance work was outside the roadway, but the expense appears to average about equally upon the roadway itself and on the roadside for a number of years.

By 1905, 63.19 miles were maintained by nine contracts and the remainder of the maintenance work was done by day labor under the supervision of a division engineer. In 1906 contracts were in effect in 28 cities and towns, and there were nearly 86 miles under this system. Many of the roads were considered of too short sections to be economically maintained under contract.

Under the contract system one man was employed, who furnished a horse, cart, and small tools. He was required to pick up stones, fill incipient ruts, supply new binder, pull weeds, fill any washouts, and, in general, to keep the road and roadside in good repair.

In 1908 the number of miles maintained by contract had decreased to 71, and the average cost was $52.18 per mile. There were 12 contracts in force with an average length of 5.88 miles. The maximum mileage was 10.47. Since that time there has been no disposition to extend maintenance by contract. Maintenance by surface treatment with bituminous material has been largely adopted and the work is done under the supervision of the engineers of the State highway commission. The following table shows the expenditure by the State for repair, including resurfacing, and maintenance of its roads for the years 1896–1912, inclusive:

TABLE XXIII.—*Massachusetts repair and maintenance expenditures.*

Years.	Total miles maintained.	Total State aid.	Cost of maintenance per mile.	Years.	Total miles maintained	Total State aid.	Cost of maintenance per mile.
1896	62	$4,727	$76	1905	548	$57,456	$105
1897	109	13,267	122	1906	610	68,382	112
1898	160	20,661	129	1907	655	106,189	162
1899	206	24,538	119	1908	702	229,666	327
1900	250	33,562	134	1909	740	402,116	543
1901	296	31,061	105	1910	784.63	504,061	642
1902	358	59,943	167	1911	828.65	530,904	647
1903	415	55,083	133	1912	879.6	594,574	676
1904	482	51,896	107				

Under the Massachusetts law of 1900 the State must be reimbursed for maintenance charges by the localities to an amount not exceeding $50 per mile. The amounts given in the column headed "State aid" include all money subsequently returned to the State under this act, and also the automobile revenues applicable to repair and maintenance. Previous to the year 1908 the motor-vehicle-fees fund was not available for highway purposes.

NEW YORK.

New York State made direct appropriations for repair and maintenance of State and State-aid roads beginning in 1907. In the year 1909 the repair and maintenance of State and county highways was put in charge of the first deputy highway commissioner. The work of the bureau of maintenance was organized with six assistant superintendents of repairs in charge of all maintenance, except resurfacing, in the respective subdivisions of the State. Each superintendent of repairs was assisted by a number of highway inspectors in charge of the roads in one or more counties, aggregating from 60 to 100 miles. The highway inspectors have direct oversight of road patrolmen. The maintenance system, then, is essentially, beginning with 1909, a system of continuous small repair by patrolmen, supplemented by resurfacing and surface treatment, directly supervised by the engineers of the commission.

The patrolman must furnish a horse, cart, and small tools. He is supplied with all road material by the State. His work is directed toward preventing unnecessary deterioration of the metal surface. He must clean all waterways and ditches, lower the shoulders of the road, fill ruts, and make other minor repairs, including repairs of guardrail, and prevent raveling by supplying binder from time to time. His hours are from 8 a. m. to 5 p. m., which allows him one hour for coming to work and one hour for leaving. Supplied with a small heating outfit for bituminous material, the patrolman can apply small patches of $\frac{3}{4}$-inch stone and fill ruts on bituminous-treated roads. As he becomes more efficient, it is possible to put him in charge of assistants and accomplish larger jobs of recapping the road. He must also spread fine stone to take up excess of bituminous material on the surface.

The patrolman is employed continuously and has charge of approximately 5 miles of water-bound macadam road, 8 miles of asphaltic macadam road, or from 12 to 15 miles of brick road on an average. Where road sections are too far apart, the length is necessarily reduced and the patrolman gives only a part of his time to the work. The work done by the patrolman is largely of a preventive nature and the results are regarded as successful. Bituminous material is supplied for the patrolman's use in barrels, and the screenings and stone or good gravel are stacked along the roadway. There are now

702 patrolmen, paid $78 per month, or $3 per day. The inspectors supply necessary instructions to the patrolman and supervise his work. They also see that he is supplied with material.

The patrolman is required to make a post-card report covering each day's repairs once a week to the highway inspector. The highway inspector in charge of the patrolmen on his mileage reports daily to the superintendent of repairs, who in turn reports to the first deputy highway commissioner.

In addition to the regular inspectors, a special inspector is employed, who is responsible directly to the commission. He is furnished with a list of all employees and their road sections. This special inspector at irregular times visits the patrolmen to see that they are properly performing their duties. A patrolman found off his work by his inspector is promptly discharged.

It is expected that the roads more recently constructed with bituminous binder and other roads with similar top dressing can be maintained under the patrol system at a minimum expense. Much of the work of applying a top course of fine stone and oil can be accomplished by the regular patrolman, with outfits owned by the State and under the direction of the division superintendent of repairs. Repair work of considerable magnitude, such as resurfacing, is done by contract, under plans and specifications, and is handled by the division engineer. Repairs not let by contract may be handled by the county superintendent directly, when turned over to him by the State commission, and the work is done under the direction of the superintendent of repairs.

It is estimated by the department of highways that when the patrol system is well established the cost will be approximately $125 per mile per year.[1] The following table shows the maintenance and repair expenditures for all State and county roads in New York for the years 1907–1912, inclusive:

TABLE XXIV.—*Maintenance and repair appropriations by the State of New York.*

Year.	Miles.	Amount available.	Rate per mile.	Year.	Miles.	Amount available.	Rate per mile.
1907	667	$205,904	$309	1910	2,123	$2,122,763	$1,001
1908	978	371,227	379	1911	2,623	1,015,253	[1] 387
1909	1,987	1,350,000	679	1912	3,100	3,127,949	1,009

[1] Appropriation late; repair work not completed.

In 1909 the bureau of town highways was established for the purpose of organizing the management of all the town or earth roads which are not to be improved as State or county highways. The mileage of such roads is at present 77,000. This bureau controls the distribution of State-aid money for *town roads*, and its work supersedes the work done under the so-called Fuller-Plank Act of 1898.

[1] During the year 1912 there were 735 patrolmen in charge of the maintenance of about 3,100 miles. The cost of the patrolmen's service was $137.12 per mile.

For purposes of administration the State is subdivided into 10 districts, each in charge of a district supervisor. There is one county superintendent in each of the 57 counties, and there are also 934 town superintendents in the various towns. Under the original law rules and regulations have been formulated for the guidance of county and town officials. Public meetings must be held once each year in each county for the purpose of instruction and information of the local officers and for the discussion of road problems. A uniform system of town accounts has been established, and all accounts are supervised and audited by the bureau. Money raised by the town and the State-aid fund is in the custody of town officials. The law requires an estimate from each town superintendent on or before October 31 of each year, and all road funds are constantly under the supervision of the State highway commission. Expenditures of all moneys must be approved by the commission, and the supervision of the representatives of the commission is extended to actual field work in the different towns.

Widening and grading must be done systematically and thoroughly, and haphazard work in applying gravel or crushed stone is not allowed. Special mention is made in the reports of the commission of the excellent results which have been achieved in bridge and culvert work. Under the direction of the bureau, town superintendents have constructed reinforced concrete bridges with standard plans. There have been built, in fact, 10,000 permanent culverts and 900 bridges. Each district supervisor is required to keep in close touch with all town highway affairs in his district and systematically to inspect the work in the towns. He must also investigate complaints and examine the condition of highway accounts.

The following table shows the county, town, and State appropriations under the Fuller-Plank Act and the bureau of town highways for the years 1899 to 1912, inclusive:

TABLE XXV.—*New York town roads expenditures.*

Years.	Miles money system roads.	State aid for maintenance.	County and town appropriation.	Cost per mile.
1899	3,696	$34,517	$138,070	$47
1900	6,497	54,057	222,767	43
1901	7,521	67,555	269,994	45
1902	11,681	102,509	419,491	45
1903	24,372	272,249	672,734	38
1904	30,952	393,493	917,873	42
1905	36,857	483,355	1,062,803	42
1906	38,857	594,591	1,206,462	46
1907	48,190	721,849	1,881,041	54
1908	54,745	1,062,674	1,757,583	52
1909	[1] 79,632	1,441,751	2,526,612	50
1910	[1] 79,646	1,591,911	4,673,962	78
1911	[1] 77,000	2,000,000	6,800,000	112
1912	[1] 67,451	1,665,500	6,938,694	103

[1] Town road system under bureau of town highways.

ROAD MANAGEMENT IN ENGLAND.

In 1888 [1] the local government act placed all road work in charge of the county councils, district councils, and urban councils. These units may be combined in the county councils. The central government board exercises general supervision. The county councils have control of all main roads in the county, including the building and maintenance of bridges. The urban authorities may, however, retain the right to maintain roads within their boundaries, and counties may contract with districts to maintain all roads, which remain, however, under the supervision of the county surveyors. In each county the work is in charge of a county surveyor, with an assistant foreman and roadmen. The surveyors are appointed by the county council and are usually associate members or members of the Institute of Civil Engineers.

The English system under the law of 1888 is essentially a local system. In 1909, by the act known as "the development and road improvement funds act," the English road board was established. The board consists of five members and is a national body. It met for the first time in May, 1910, and issued an annual report in August, 1911. A consulting engineer and an advisory engineering committee of six members have been selected. Under the law the road board has the power to advance money to county councils and other highway authorities for the construction of new roads or for the improvement of existing roads, and also to construct and maintain any new roads which appear to be required. Improvement is construed to include the widening of the road, the improvement of the alignment, the reduction of the grades, the treatment of the road for mitigating dust, and certain other work beyond ordinary repairs. The authority of the board extends throughout the United Kingdom.

The road board administers the road improvement fund, which consists of the revenue obtained from motor-spirit (gasoline) duties and motor-car licenses. The total receipts of this fund, including interest, from May, 1910, to March 31, 1912, were £2,184,314. Of this amount £541,937 was granted and loaned for road improvement during the interval mentioned, and nearly all the remainder,[2] after deducting administrative expenses, was invested. Up to March 31, 1912, grants by the road board had been made as follows:

Improvement of road crusts	£421, 949
Road widening and improvement of curves and corners	56, 833
Road diversions	18, 276
Reconstruction and improvement of bridges	15, 128
New roads and bridges	4, 928
	517, 114

[1] First International Roads Congress, Paris, 1908. Report by Carpenter.

[2] Indicated grants amounted to £534,[illegible]34 additional.

In setting the amount of a grant the board attempts to pay 75 per cent of the net cost of the improvement contained in the work, after due allowance is made for the element of maintenance contained in improved surfacing. The policy of the board is to encourage the use of bituminous binding materials in improvement of road crusts.

The schedule of motor-vehicle taxation is as follows:

TABLE XXVI.—*Annual duty assessed in England.*

Items of taxation.	Amount in English currency. £ s. d.	United States equivalent.
Motor bicycles and motor tricycles of whatever horsepower	1 0 0	$4.86
Motor cars:		
Not exceeding $6\frac{1}{2}$ horsepower	2 2 0	10.21
Exceeding $6\frac{1}{2}$, but not exceeding 12 horsepower	3 3 0	15.31
Exceeding 12, but not exceeding 16 horsepower	4 4 0	20.14
Exceeding 16, but not exceeding 26 horsepower	6 6 0	30.62
Exceeding 26, but not exceeding 33 horsepower	8 8 0	40.82
Exceeding 40, but not exceeding 60 horsepower	21 0 0	102.06
Exceeding 60 horsepower	42 0 0	204.12

A tax is levied on "motor spirits" or gasoline manufactured or imported at the rate of 3d. per gallon. Manufacturers of gasoline pay £1 annually for a license and dealers 5s.

The following table shows the entire cost of main roads in the county of Notts, England, from 1891 to 1911:

TABLE XXVII.—*Main roads expenditures, County of Notts, England, from 1891–1892 to 1910–1911.*

Year.	Mileage.[1]	Average cost per mile of maintenance.	Average cost per square yard.	Year.	Mileage.[1]	Average cost per mile of maintenance.	Average cost per square yard.
1891–92	$303\frac{1}{2}$	$270	$0.025	1901–2	$326\frac{3}{4}$	$270	$0.025
1892–93	$305\frac{1}{4}$	278	.026	1902–3	$326\frac{3}{4}$	278	.026
1893–94	$305\frac{1}{4}$	284	.026	1903–4	$326\frac{3}{4}$	304	.028
1894–95	$312\frac{1}{2}$	260	.024	1904–5	$326\frac{3}{4}$	325	.030
1895–96	$312\frac{1}{2}$	253	.023	1905–6	$326\frac{3}{4}$	316	.029
1896–97	$312\frac{1}{2}$	254	.023	1906–7	$326\frac{3}{4}$	315	.029
1897–98	319	258	.024	1907–8	$326\frac{3}{4}$	380	.035
1898–99	319	260	.024	1908–9	$326\frac{3}{4}$	382	.035
1899–1900	$326\frac{3}{4}$	255	.023	1909–10	$326\frac{3}{4}$	405	.037
1900–1	$326\frac{3}{4}$	265	.024	1910–11	$326\frac{3}{4}$	433	.040

[1] 3,568,000 square yards. In a road of average width (18.6+feet)=10,912 square yards per mile.

The two following tables show the average cost of the main roads in the division of Lindsey, Lincolnshire, England, for 30 years and in Yorkshire for the past 22 years.

TABLE XXVIII.—*Cost of main roads, Lindsey, Lincolnshire.*[1]

Year.	Cost per mile.	Year.	Cost per mile.	Year.	Cost per mile.
1881	$295	1891	$260	1901	$344
1882	292	1892	296	1902	354
1883	286	1893	366	1903	330
1884	298	1894	314	1904	310
1885	256	1895	309	1905	353
1886	318	1896	328	1906	345
1887	276	1897	354	1907	368
1888	271	1898	340	1908	425
1889	278	1899	292	1909	400
1890	293	1900	311	1910	413

[1] From statement of cost of main roads for the year ended Mar. 31, 1910.

TABLE XXIX.—*Cost of main roads in Yorkshire.*

Year ended March 31—	Total cost, including grants toward improvement works on expenditure on burr[1] walls.	Approximate length (miles).	Average cost per mile.	Year ended March 31—	Total cost, including grants toward improvement works on expenditure on burr[1] walls.	Approximate length (miles).	Average cost per mile.
1890	$461,581	1,006	$481.74	1901	$768,223	1,111	$691.47
1891	523,639	1,006	520.51	1902	772,754	1,107	698.06
1892	559,536	1,006	556.20	1903	775,715	1,104	702.64
1893	664,084	1,073	618.90	1904	816,759	1,094	746.58
1894	710,767	1,097	647.91	1905	836,377	1,094	764.51
1895	714,669	1,122	636.96	1906	886,435	1,094	810.27
1896	722,119	1,122	643.59	1907	872,917	1,094	798.92
1897	766,759	1,122	683.38	1908	898,251	1,094	821.08
1898	804,065	1,125	714.72	1909	953,007	1,094	871.10
1899	791,150	1,128	701.38	1910	944,354	1,094	863.21
1900	746,296	1,133	658.68	1911	1,029,909	1,094	941.42

[1] Foundation retaining wall, often out of sight.

The cost of repair and maintenance of rural main roads in England and Wales by the county councils[1] for the years 1903 to 1910 throughout is shown by the following table:

TABLE XXX.—*Cost of repair and maintenance in England and Wales.*

Year.	Total expenditure.	Miles.	Cost per mile.	Year.	Total expenditure.	Miles.	Cost per mile.
1903–4	$5,887,127	16,768	$350	1907–8	$6,556,079	17,536	$375
1904–5	5,964,863	16,970	350	1908–9	6,914,205	17,687	388
1905–6	6,193,332	17,468	355	1909–10	7,401,324	17,800	415
1906–7	6,204,680	17,480	355				

The above roads are strictly country main roads outside of cities, under the direct control of the county councils, and are about 12 per cent of the total road mileage of England and Wales.

In general English roads were formerly maintained by a patrol system by which a roadman with a donkey cart covered about 4 miles.

[1] From the Thirty-ninth and Fortieth Annual Reports of the local government board.

This system is still used in some rural communities. The use of refined tar has now been largely adopted on main roads, and the above tables included resurfacing with such material by various methods. It is characteristic of recent bituminous work in England that no dust whatsoever is allowed in any material used. Sprinkling roads with water has been largely abolished, but the cost of washing and cleansing is a maintenance charge.

The latest figures obtainable present the mileage of roads in Great Britain as follows:

England and Wales	150,692
Scotland	24,771
Ireland	[1] 55,562
Total	231,025

There are about 27,802 miles of "main roads" in England and Wales, of which approximately 10,000 miles are urban "main roads," or roads in urban districts. The expenditure on the total mileage (27,802) of main roads for the year ending March 31, 1909, was £2,895,483 of which maintenance and repair amounted to £2,643,044 or about $475 per mile.

The increase of automobile traffic in the United Kingdom is shown in the following table of motor vehicles of all kinds:

Table XXXI.—*Motor vehicles in Great Britain.*

1904	51,549	1907	125,320
1905	74,058	1910	218,680
1906	86,536	1911	266,258

The cost of maintenance in England and Wales in extra metropolitan county boroughs has risen 81 per cent from 1890 to 1909, but the rate of increase has not been greatest in the period of greatest development of motor traffic, as has been generally supposed. The average annual rate of increase in maintenance expenditures from 1890 to 1902 was 5.9 per cent and from 1902 to 1909, 1.4 per cent.

ROAD MANAGEMENT IN FRANCE.

The roads of France have a total length of about 360,000 miles, classified as follows:

(1) National roads, built and maintained by the National Government, 23,756 miles; (2) departmental roads, built and maintained by the Departments traversed, now generally under supervision of the engineers of the Ponts et Chaussées, 8,161 miles; and (3) vicinal roads, including (*a*) principal communal roads, traversing two or more

[1] Report of the Second Irish Road Congress, 1911.

communes and maintained by them with Government aid, 107,049 miles; (*b*) secondary communal roads maintained by the communes, 47,256 miles; and (*c*) ordinary vicinal roads, maintained by the communes under the supervision of Government engineers, 177,550 miles.

Rural roads and lanes of small importance, about 9 feet wide on the average and maintained entirely by the communes, add about 155,376 miles.

The cost of the national roads was $303,975,000. They have a width of from 32.8 to 45.9 feet, with a metaled driveway from 16½ to 23 feet wide. The depth of the road is about 8 inches. In exceptional cases and near large cities the width of the road is increased and the driveway paved instead of macadamized. The cost of constructing 316,900 miles of the roads classified under Nos. 2 and 3 is given as $308,800,000, of which the Government's contribution was $81,060,000.

The superiority of the French road system is not due to any extraordinary natural conditions or advantages, but to the efficiency of the administrative organization. The basis of the administrative system is the publicly maintained École des Ponts et Chaussées, where the road engineers and officials receive their technical training. A regularly recruited corps of trained and experienced men is thus constantly in charge of all the important roads. The department of the Ponts et Chaussées constitutes also a centralized source for information concerning the roads of the entire country.

For the purpose of road maintenance and construction the organization is as follows: (1) Inspectors general of bridges and highways; (2) chief engineers, charged with the work of a "département"; (3) ordinary engineers and under engineers, charged with an "arrondissement"; (4) principal and ordinary conductors, charged with a subdivision; and (5) cantonniers, each having from 4 to 7 kilometers (2.48 to 4.05 miles) of highway under his immediate supervision.

The cost of maintaining the roads in France is gradually increasing. In 1893 the cost of maintaining 22,009 miles of national roads was $225 per mile. In 1900 the cost of maintaining 23,660 miles of the same roads was $230 per mile. By 1906 the national roads had attained a length of 23,742 miles and the cost of maintenance was $315; in 1907, $323; in 1908, $349; and in 1909, $347. The cost of maintaining the departmental roads has remained more nearly stationary. From 1886 to 1888 the average cost of maintenance was $172 per mile, while from 1900 to 1905 the cost ranged from $180 to $182 per mile.

TABLE XXXII.—*Road maintenance in France on the national roads (23,756 miles in length).*[1]

Items of expenditure.	1906 (francs [2]).	1907 (francs).	1908 (francs).	1909 (francs).
Ordinary repairs	29,512,809	29,325,074	30,072,663	30,157,643
Streets (Paris)	3,000,000	3,000,000	3,000,000	3,000,000
Extraordinary repairs	1,702,803	1,722,069	4,271,574	3,805,502
Pension fund (cantonniers)	450,793	450,822	450,743	445,377
Bureau du Service des Ponts et Chaussées	....	810,616	788,980	[4] 785,067
Salaries, etc. (393 engineers [3] and "conducteurs")	3,798,409	3,442,096	3,406,847	[4] 3,383,031
Salaries, etc. (2,113 under engineers and "conducteurs")	7,710,561	7,470,445	7,331,586	[4] 7,770,802
General expenses of the service	1,370,222	1,363,340	1,398,574	[4] 1,309,413
Total maintenance and general expenses	47,545,597	47,584,462	50,720,967	50,656,835
Cost of maintenance per year per mile	$315	$323	$349	$347

[1] From the reports of the minister of public works.
[2] United States equivalent is $0.193.
[3] The engineers of the Ponts et Chaussées perform a multitude of duties aside from the supervision of the "routes nationales."
[4] In deriving the cost per mile, 40 per cent of the above engineering and general expenses were assessed against the maintenance of the "routes nationales."

The roadmen who perform the manual labor on the roads of France are known as the "cantonniers" and number between 8,000 and 9,000. These men are nominated by the prefect and are required to be experienced in road work and to be not more than 35 years of age when appointed. They must have fulfilled their military duty and be sound workmen of good character. They have charge, on the average, of somewhat less than 3 miles of road each and give their whole time to the road work, with the exception of certain hours of leave during the summer. The "cantonniers" are paid about $174 per year, with certain perquisites as to lodges, etc., and it is common for them also to work small farms or gardens. Each "cantonnier" is supplied with a detailed list of instructions in his duties and with road materials, and his work is directed by the engineers.

AUTOMOBILES.

The development of automobile traffic upon public highways within the past decade is perhaps the most significant influence affecting the road problem since MacAdam's time. The number of automobiles, including commercial vehicles, registered in the United States in the year 1912 was 1,013,975, and the total number of machines in use during the same time was nearly 1,000,000. The total mileage of improved roads at the close of 1912 was approximately 222,081. There were then nearly five automobiles to each mile of improved highway.

Automobile traffic in all forms is rapidly increasing. In 1909 the traffic census at 238 stations in Massachusetts showed an average number of 96.1 motor vehicles, which was 39 per cent of the total number of vehicles per day. In 1912 the average number of motor vehicles in the same State at 156 representative stations was 222, which was 63 per cent of the total number of vehicles per day, and showed an increase of 131 per cent in three years.

TABLE XXXIII.—*State automobile revenues.*

State.	1903	1904	1905	1906	1907
California [1]			$7,857	$11,240	$15,830
Connecticut					11,686
Delaware [1]					1,586
Illinois					17,541
Maine			1,472	1,298	1,708
Massachusetts	$17,684	$19,162	24,490	33,085	92,091
Michigan [1]				8,352	12,798
Missouri [1]					13,168
New Jersey				55,000	56,473
New York	[2] 9,181	14,249	25,953	35,463	44,580
Pennsylvania				42,460	59,604
Rhode Island			1,684	2,146	2,330
South Dakota			365	450	700
Washington [1]			688	1,494	2,746
West Virginia [1]				1,718	2,075
Total	26,865	33,411	62,509	192,706	334,916

State.	1908	1909	1910	1911	1912
Alabama [1]				$55,000	$64,489
Arizona				7,400	12,323
Arkansas [1]				7,750	15,000
California [1]	$16,970	$19,048	$30,495	50,445	[3] 50,000
Colorado [4]				47,000	[3] 50,000
Connecticut	61,747	57,567	159,174	230,925	[3] 250,000
Delaware [1]	2,175	5,472	9,399	13,279	17,988
Florida				2,900	10,052
Georgia [1]			6,900	13,674	12,000
Illinois	13,329	30,827	45,468	124,239	364,873
Indiana [1]			[5] 32,000	13,000	17,009
Iowa				178,814	404,862
Kentucky			23,340	23,355	37,260
Louisiana				24,000	[6] 30,000
Maine	2,248	3,342	4,938	7,340	102,801
Maryland				56,210	95,000
Massachusetts	121,488	169,974	403,301	504,162	616,236
Michigan [1]	5,682	8,291	73,801	106,913	143,388
Minnesota [1]				28,912	43,500
Mississippi					25,855
Missouri [1]	11,123	20,503	31,527	55,506	117,362
Nebraska		17,054	29,532	47,114	20,462
New Hampshire			42,421	58,009	117,316
New Jersey	82,000	280,828	335,578	[7] 350,000	469,471
New Mexico					9,040
New York	53,736	81,773	397,540	918,197	[3] 1,000,000
North Carolina [1]				[8] 12,010	12,582
North Dakota				17,602	28,398
Ohio		46,577	124,000	190,712	337,303
Oklahoma				17,245	2,831
Oregon				27,316	43,132
Pennsylvania	75,646	103,410	321,985	429,523	597,723
Rhode Island	31,108	50,266	66,056	82,764	104,689
South Carolina [1]		[4] 850	[4] 1,800	[4] 2,100	3,261
South Dakota	841	2,102	3,010	4,111	1,492
Tennessee [1]		2,102	3,190	4,558	7,238
Texas				78,000	[3] 80,000
Utah		1,952	1,287	1,165	[3] 1,800
Vermont		25,218	40,000	60,635	80,799
Virginia [1]			20,670	35,576	57,440
Washington [1]	3,184	8,554	12,002	20,636	28,000
West Virginia [1]	3,000	3,150	8,020	13,378	[3] 23,000
Wisconsin				[9] 46,000	124,303
Wyoming					[3] 8,600
Total	484,277	938,860	2,227,434	3,967,475	5,638,878

[1] Revenues not applicable to roads.
[2] 1901 receipts, $954; 1902, $1,082.
[3] Estimated by State officials and Office of Public Roads.
[4] No State registration.
[5] Total receipts, including 1910.
[6] Estimated—bill pending.
[7] Net, above expenses.
[8] Fiscal year ending June 30 each year.
[9] The fee was $2 for each automobile.

The increase in automobile gross revenues paid into the State treasury in 36 States during the last 10 years is presented in Table XXXIII. In the majority of States the automobile revenue, after deducting the cost of its collection, is applied to the repair and maintenance of State and State-aid roads. Some of the States, however, did not use the automobile revenue for maintenance.

A very important and interesting law was passed by the 1913 legislature in the State of Maine. This act provides for an issue of bonds to the amount of $2,000,000 for the purpose of constructing State roads. These roads are to be built entirely by the State and are to be maintained by the State. The charge for maintenance against those towns in which the roads are maintained shall be

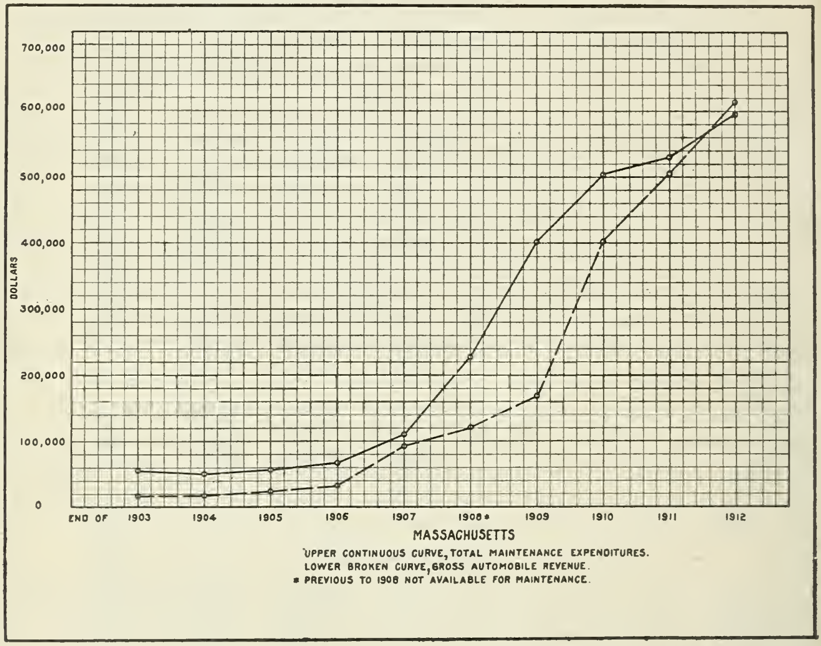

FIG. 13.—Relation between maintenance expenditures and gross automobile revenue in Massachusetts.

the actual cost up to and not exceeding $60 per mile. The interest and retirement fund for the bonds is to be derived entirely from the automobile revenues. The schedule of charges for registration and licensing of automobiles has been definitely determined and will produce a sufficient annual fund for the purpose in hand. The exact character of these bonds has not yet been determined, but they will run for a maximum period of 41 years, with interest not exceeding 4 per cent. Maine is therefore the first State which has seen fit to capitalize automobile revenues for construction of highways. Under the plan adopted not more than $2,000,000 can be outstanding at any one time and not more than $500,000 can be issued in any one year.

The determination of an economic rate of taxation of automobiles becomes very important when the cost of tire renewals, which must in part depend upon road conditions, is taken into consideration. If the average mile cost of tires per automobile is taken at 1.5 cents, the passage of 75 automobiles daily is equivalent to $411 per mile per year. It is quite evident then that a considerable reduction in tire costs by the improvement of road maintenance would justify a material increase in automobile fees. The preceding diagram (fig. 13) shows the relation between total maintenance expenditures and gross automobile revenue in Massachusetts for the past 10 years.

Table XXXIV shows the increase in automobile gross revenue per mile of State and State-aid roads in from 1 to 21 States. The average amount per mile is obtained by dividing the total automobile revenue for a given year by the corresponding total mileage for that year.

TABLE XXXIV.—*Automobile revenues per mile of State-aid and State roads.*

Year.	Number of States.	Total mileage.	Total automobile revenues.	Revenues per mile.
1903	1	791	$26,865	$34
1904	1	949	33,411	35
1905	3	901	27,646	31
1906	8	2,678	179,297	67
1907	10	3,807.85	285,602	75
1908	10	4,615.57	439,014	95
1909	13	8,735	872,099	99
1910	15	11,271.61	2,056,333	182
1911	17	14,831.33	3,970,263	219
1912	21	17,454.33	5,491,677	265

CONCLUSION.

No one at this time can predict the extent to which motor vehicles will be found on the highways of the United States within the next 10 years. It does not seem probable that the present rate of increase will continue as far as motor cars are concerned. On the other hand, the use of automobile trucks for commercial purposes is rapidly increasing. The final estimate of the economic advantage of using automobile trucks must certainly include as a factor the increased cost of construction and maintenance required upon highways. There are already marked tendencies toward increasing the strength and durability of road foundations and toward the adoption of more costly road surfaces with a proportionate low cost of maintenance. It is not uncommon now to find upon the main traveled roads both brick and concrete surfaces in addition to the already common bituminous-bound macadam.

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